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Understanding the Complexity of Project Team Member Selection through Agent-Based Modeling

Abstract

Previous research has recognized the significance of a team's work capacity and suggested the selection of team members based on individual skills and performance in alignment with task characteristics. However, work teams are complex systems with interdependence between workers and the social environment, and exhibit, surprising, nonlinear behavior. This study utilizes Agent-Based Modeling (ABM) to understand the complexity of project team member selection and to examine how the functional diversity of teams and worker interdependence affect team performance in different economic conditions. Data for model validation was collected from 116 construction projects for the period from 2009 to 2011. The results show that teams with higher functional diversity can enhance the overall firm performance when the economy is in a downturn. This study suggests managers using knowledge of worker interdependence to protect higher-performing workers by minimizing disruption of interdependence in team member selection for improving firm performance.

Keyword: Team member selection, Diversity, Interdependence, Complexity, Agent-Based Modeling

Introduction

Businesses are using teams for project-based tasks with greater frequency because teams have high potential, high motivation, good problem-solving capability and flexibility which are important work structures for success (Gordon 1992; Gerard 1995; Baykasoglu et al. 2007). A team is typically defined as a small group of people working in an interactive manner toward a common goal (Ilgen 1999;

Wageman et al. 2012). The success of these project teams is highly dependent upon the people on the team. While the literature has focused on other methods for improving team performance, such as training and feedback, team member selection and member replacement are the tools that managers use the most often (Solow et al. 2002).

Previous research has recognized the significance of a team's work capacity and suggested the selection of team members based on individual skills and performance in alignment with task characteristics. However, work teams are complex systems with interdependence between workers and the social environment, and exhibit, surprising, nonlinear behavior. In order to understand the complexity of project team member selection, this paper first reviews the relevant literature both in project management and organization science. Agent-based modeling (ABM) was selected to model team member selection because it especially designed to model interactions between agents and environments. For empirical comparison, this study uses a small design firm to examine the performance of a variety of team member selection approaches. Project data, task assignment, and team performance information were collected for the period of 2009-2011 and used to validate the developed ABM team member selection model. Using simulation, together with insights derived from complex systems, this study then illustrates that ABM provides a suitable platform for the creation of robust and accurate "what-if" scenarios within team member selection settings. This approach can simulate multiple alternative configurations of teams to predict and evaluate their performance, which in turn, can provide a decision support tool for tactical and operational decision-making in the context of project team member selection.

Project Team Member Selection

Although research on project teams has increased in recent years (Bartsch et al., 2013; Ding et al., 2014; Buvik and Rolfsen, 2014; Savelsbergh et al., 2015), any researchers doing a study of project teams may struggle to describe exactly what kind of project team is the focus of his or her study. According to the dimensional scaling framework for describing teams which developed by Hollenbeck et al. (2012), the project team that discussed in this research can be classified as Long-term project teams. The long-term project team is a team that is a stable and permanent unit in an organization. Compared to short-term project team, the task requirements may be more stable, and distribution of tasks and roles also be more clearly defined (Joshi and Roh, 2009). In terms of temporal stability, the long-term project teams are defined for those who work together up to a year on specific projects.

During the 1980s and 1990s, several researchers focused on selecting team members based on complementing personalities (Barry and Stewart, 1997; Hogan et al., 1988; Smith-Jentsch et al., 1996). Moreover, the self-efficacy for teamwork and self-monitoring has been shown to impact team effectiveness, but the relationship between these attributes and individual team performance has not yet been investigated (McClough and Rogelberg, 2003). Past research demonstrated that personality-based selection is useful in general; however ability-based selection strategies have historically been more successful in predicting performance (Hunter et al., 1990; Schmitt et al., 1984).

Although it is simpler to study team performance as an accumulation of individual contributions and assuming each person's contribution is independent of others, many researchers have realized the importance of interdependence and non-additive contributions (Hinds et al., 2000). Tziner and Eden (1985) discovered in their study of military tank crews, highly skilled teams far outperformed the levels predicted from summing their skill levels, and low-skilled teams performed well below the predicted levels of their summed skills. They used these observations about synergistic performance to offer detailed recommendations for building three-man tank crews from the existing candidate pool. They also noted that switching operators between crews was not a zero-sum game in which one team lost what the other gained. Instead, some combinations of players performed disproportionately better or worse than others. Thus, optimizing individuals to fit activities without taking interdependencies into account is unlikely to yield a high performing team. Otherwise, obtaining empirical data about the effects of different team member selection orientations on team performance can require a prohibitive time commitment. This study instead utilizes a computational model to understand the complexity of project team member selection and to maximize performance across workers and teams in different contexts.

Complex Systems and Agent-Based Modeling

A complex adaptive system (CAS) is a special kind of complex system since it has the property of adaptation, meaning that it has the "ability to consciously alter its system configuration and influence its current and future survival" (McCarthy, 2003). An agent in a CAS may be a person, a molecule, a species, or an organization, or any number of other object types. These agents act based on local knowledge and conditions. A central body, master neuron, or a project manager does not control the agent's individual moves. A CAS often has a densely connected web of interacting agents, each operating from its own schema or local knowledge. In a construction project context this means that the entities in the system are responsive, flexible, reactive and often deliberately proactive in response to inputs and signals from other nearby entities. Many business processes and phenomena are non-linear, self-organizing, changing and rationally bounded, and so CAS can yield unique insights into these processes and phenomena. While insights from CAS can improve our understanding of project team member selection and provides a helpful framework for modeling, some kind of method is needed in order to apply this approach and achieve tangible and understandable results, particularly from a management perspective.

Agent-based modeling (ABM) represents a new paradigm in the modeling and simulation of dynamic systems distributed in time and space (Jennings and Bussmann, 2003; Lim and Zhang, 2003). ABM enables the application of CAS approaches to address the behavior of each of the participants within a complex system (North et al., 2005). There is a growing interest in using ABM in several business-related areas, such as manufacturing (Kotak et al., 2003; Zhou et al., 2003), logistics and supply chain management (Kaihara, 2003; Santos et al., 2003), marketing (Rand and Rust, 2011), and operations research and management science (Davis et al., 2007). ABM is considered important for developing industrial systems (Davidsson and Wernstedt, 2002; Fox et al., 2000; Karageorgos et al., 2003) and it provides a pragmatic approach for the evaluation of management alternatives (Swaminathan et al., 1998). The simulation of teams has been undertaken by several researchers, reflecting the large number of team-based activities available (Fan and Yan 2004), but just a few in project organization (Aritua et al., 2009; Watkins et al., 2009; Kim and Kim, 2010).

In ABM, the focus is on agents and their relationships with other agents or entities (Axelrod, 1997; Cicirello and Smith, 2004). An organization is a collection of agents that interact and produce some form of output. Organizations have output and deliver some measure of performance. Performance may be measured by profit or may involve specifying a particular target and then measuring performance by the frequency with which organizations reach their targets. Although most organizations are designed with a particular objective, it does not follow that the organization's behavior is consistent with this objective. The members of an organization may have different goals than those of the entrepreneur/head of the organization. Using ABM it is possible to observe how an organization's behavior emerges from the interaction of agents amongst themselves and with the environment. Given these various characteristics, ABM is an appropriate research tool for examining team member selection in the project organization domain. In this study, the workers are modeled as agents and the organization performance is measured by profit earned. The detail description of the model is demonstrated in the following sections.

Description of the Project Team Member Selection Model

One way to make ABM more understandable and comprehensible is through the use of a standard method of description. To bring the benefits of standardization to ABMs, a group of experienced modelers (Grimm et al., 2006; Grimm and Railsback, 2005) developed the Overview, Design concepts, and Details (ODD) protocol for describing ABMs. ODD is designed to create factual model descriptions that are complete, quick and easy to grasp, and organized to present information in a consistent order. ODD is now gaining widespread acceptance in the ecological and social science literature (Grimm et al., 2010). A full ODD protocol description is too long to fit in this paper, but we will use the overview part of the ODD protocol to set up the model. The overview consists of three components: (1) a description of the purpose of the model, (2) a description of the state variables and scales, and (3) an overview of the process and scheduling aspects.

Purpose

The purpose of the model is to examine and compare different team member selection orientations in different contexts. First, it is necessary to establish what is meant by team performance. Although it has been defined in numerous ways, three key performance variables have emerged: the quality of a team's output, the amount of time taken to deliver this output, and the cost of doing so. Within engineering and project management fields, these three variables – quality, time, and cost – are often collectively referred to as the triangle for evaluating performance. In this model, we assume that all projects meet basic requirements, i.e., the selected teams perform well on the projects without quality issues and complete projects within the planned duration. The criterion of team performance evaluation here is profit generated by the team. Profit was chosen as the criterion because it can easily show the teams' outcome and can clearly demonstrate the difference when comparing those team member selection orientations.

An ABM environment is developed for a project-based company, a small construction design firm. There are two major reasons why we chose a small design firm. First, we chose this firm because we would like to simplify the economic context. Small firms usually target local markets. It is easier to create a reasonable environment for a small firm rather than for large companies. For example, an international design firm may have projects around the world, which makes it more difficult to establish the boundaries of the market. Second, we chose this firm because we would like to simplify the interdependence of workers. Although one of the objectives of our research is to see if using knowledge about the interdependence of workers can improve project performance, it is very hard to define the interdependence matrix for a team or an organization with extremely complicated working relationships, and so a smaller firm gives us the ability to scale back the model complexity.

To explore how interdependence-based team member selection improves performance compared with skills-based assignments, three components associated with a worker's contribution need to be quantified: individual contribution, contributions to others, and contributions from others. Suppose a worker, when placed on a team, loses a connection with a co-worker who previously affected that worker's performance, then the interdependent effect needs to be taken into account. For example, the transferred employee could be a consultant put on a new project without the support of a familiar colleague with particular information technology skills. If the original interdependencies were necessary for the consultant to deliver consistent results, then the consultant will naturally seek to form a new relationship with someone on the new team with similar information technology expertise. Exchanging an established relationship with a new connection can be thought of as replacing a supportive colleague on whom a worker was interdependent with another who may or may not be as supportive. Given the interdependencies among workers, it is reasonable to assume that losing co-workers influences, either positively or negatively, the individual and collective performances of those who remain – the larger the number of losses, the greater the variance in performance. Therefore, when team member selection occurs, we can assume that a worker's performance changes in an uncertain manner.

Considering the complex nature of interaction in interdependent groups, assessing individual and team level performance can be challenging in practice (Solow et al., 2002; Millhiser et al., 2011). Many organizations document observed employee performance through periodic appraisals. However, managers are unable to see how these workers contribute to others or what portion of their performance is attributable to help from others. We utilized the NK model and Decision Support Matrix (DSM) to capture workers' interdependencies (Kaufmann, 1995; Millhiser et al., 2011). The detailed processes of different team member selection orientations and the use of ABM to compare them will be discussed in the design concept of ODD protocol.

Entities, State Variables, and Scales

ABMs usually have the following types of entities: one or more types of agents; the environment in which the agents live and interact, which is often broken into local units or patches; and the global environment that affects all agents. In this model, the variables of both agents and the projects are defined in Table 1 and Table 2. The global environment variable we set here is the economic situation. The economic situation setting is directly related to the number of projects available on the market. In order to simplify the model, the economic situation is modeled as a series of discrete states from 1 to 5. In the normal situation, the economic situation is set to 3 (neutral). If the number is set lower than 3 that mean the economic situation is in a depression. In contrast, there is economic growth if the number is set higher than 3.

In our model, the temporal scale is set as days because project duration is often counted in working days. A tick in this ABM means a day. The new projects are also announced by project owners (e.g., the government, commercial entities, etc.) every day. The agents in our model do not only work on the projects, but also prepare, evaluate, and bid on new projects. This model sets the simulation time as 3 years because the duration of most projects in the small construction design field range from 2 weeks to 1 year, and simulating 3 years can properly encompass the typical operations of a small project-based organization.

Process Overview and Scheduling

This section will address model dynamics, i.e., the processes that change the state variables of model entities. Every process describes the behavior of the model's entities. The schedules of events are illustrated in Table 3. The goal of the simulation is to explore the relative effects of different team member selection orientations on firm performance in a context. The computational model consists of agents and a schedule of events. The agents in the model are teams and projects, and the schedule of events governs the interactions among the agents. We built a simulation model of a project organization with a limited number of relevant capabilities based on employees' expertise. The market has a population of projects. These projects represent opportunities for the firm to make investments in capabilities.

Workers are selected into teams based on different team member selection orientations. Once work teams are formed, we assume that the teams will keep in stable for performance. Based on the research findings from Savelsbergh et al. (2015), team stability has direct effect on team learning which had on its turn a strong effect on team performance. The work teams can work on multiple projects, but the total workload cannot surpass their capacity. The team capacity is assumed to be equal to the sum of individual capacity. The set of team capabilities is equal to the sum of worker's capabilities (expertise). For example, if the team has workers who have expertise in road, bridge, and environmental design, the team is allowed to take the projects within the scope. The main focus of this is in comparing different team member selection orientations and demonstrating why taking into account complexity to form a team can yield better overall team performance. We assume workers have no ability to sense information about other projects, so it is reasonable to simply assume they randomly evaluate new projects. After choosing a project for evaluation, the next step is bidding and assigning the project. Teams win bids based on a random probability from 20% to 50% if the team still has available capacity. Teams will keep searching and bidding on projects until the team's capacity is full. The team's capacity will be replenished and the team will earn the expected profit when the project is completed. These processes will repeat in our model and the profit earning will be accumulated as emergence of project team performance.

Team member selection orientations

The primary mechanism that we will explore in the model results below is the team member selection orientation and its relation to the overall performance of the organization. In this section we describe the details of the three selection orientations we want to compare and the definition and performance evaluation criteria are discussed in the following sections. This section also describes how the overall performance of a project-based organization is defined and evaluated in the context of these methods.

1. Homogeneous team member selection:

Team composition can either be homogeneous or heterogeneous. There are conflicting opinions on which is best (Lim and Klein 2006). While there is increasing recognition of that diversity in team's benefits creativity in problem solving, homogeneous teams are better for exploitation of existing knowledge (Mannix and Neale 2005). The homogeneous team member selection in this paper is defined as selecting team members with similar expertise, experience, and education background. The homogeneous team is assumed to have higher capacity in particular areas.

2. Heterogeneous team (equity-based) selection:

A full discussion of the impact of diversity in complex systems (Page, 2011), and the relationship of diversity to team performance (Hong and Page, 2004) is beyond the scope of this paper, but a few broad general results are applicable. First, diversity often enhances the robustness of complex systems. Systems that lack diversity can lose functionality. Second, diversity drives innovation and productivity (Page, 2011). In economies, variation and experimentation also lead to innovation and recombination (Arthur, 1999). Greater diversity for the most part correlates with greater productivity. The equity method is characterized by dividing talents. For example, managers sometimes may allocate the most creative people evenly between teams, then the best analysts, the best salespeople, and so forth. The selected teams can be thought to result in equally capable, albeit average, teams. In this research, this method is operationalized by allocating the workers by dividing talent evenly across by experience, licensing, and other features of the workers. This method is assumed to enhance the functional diversity of each team compared to the homogeneous team member selection orientation. Functionally diverse teams are also defined as teams consist of individuals with a variety of educational and training backgrounds working together (Simons and Rowland, 2011)

3. Interdependence-based selection orientation:

In the third team member selection orientation, we utilize and modify the NK model (Kaufmann, 1995) and Design Structure Matrix (DSM) tool proposed by (Millhiser et al., 2011) to measure and capture the three components of performance – individual contributions, giving to others, and receiving from others – that affect a worker's total contribution to a team. Kauffman (1995) shows that the number of local optima increases in K, which is the number of connections between individual entities, in this case the interdependencies between team members. Rather than specify exactly the coupled or interacting activities, many models in organizational theory use the NK framework to model interaction patterns since it enables the exploration of different architectures and their effect on performance. These interdependencies are described through the use of an adjacency matrix. An example of this interdependency matrix is shown in Figure 1.

Observed performance usually reflects an individual's contribution together with whatever contributions other team members contribute to that person, but observed performance does not capture the contribution of that individual to others. What is needed is a measure of how much interdependence a worker has. Assuming that there are N workers in the original cohort, we refer to a particular team member as worker *i* (where *i* indicates the worker's number from 1 to N). Because each worker "depends on" others to accomplish tasks, we assume that a worker is interdependent on K others, ranging from complete self-reliance (K = 0) to dependence on everyone else (K = N-1).

To distinguish between the two types of interdependence, the colleagues who support a worker, those represented by an *x* in that worker's column are called contributing partners (see Figure 1); those who rely on a worker (represented by *x*'s in that worker's column) are called dependent partners. In addition to these partners, we assume every worker relies on himself or herself, as depicted by *x*'s along the diagonal. Given a worker and that worker's contributing partners, a worker's performance can be attributed to the worker and the support for that worker from the K partners who influence the worker (Millhiser et al., 2011). When a worker is assigned to a team with all the original contributing partners from the cohort, it can be assumed that the performance of that worker is unaffected. Although there are other considerations which may affect worker's performance, we only focus on the role of interdependence on team performance. In contrast, when a worker's connections are disrupted, that has a dramatic effect on their new performance capacity. The worker's performance will vary widely, perhaps as low as 0 or as high as 1 if *all* contributing co-workers are assigned elsewhere because the worker needs to establish new relationships with other team members to accomplish the project. When contact with some, but not all, contributing partners occurs, the new performance is assumed to vary proportionally to the number of disrupted interdependencies. The new performance will be widely set between 0 and 1 based on how many disruptions of the original number of co-workers.

If worker *i*'s initial performance in the cohort is p_i and if team member selection disrupts d_i of the worker's K interdependences, the worker's new performance is called p_i', which is generated by choosing a uniform random number between some new lower and upper performance limits. The upper limit u_i is assumed to be the proportion d_i/K of the potential improvement from the current performance p_i up to 1 (maximum capacity). The lower limit l_i is the proportion d_i/K of the possible performance loss form p_i down to 0. The equations of l_i and u_i are:

$$l_i = p_i - \left(\frac{d_i}{K}\right) p_i \quad (1)$$

$$u_i = p_i - \left(\frac{d_i}{K}\right) (1 - p_i) \quad (2)$$

$$p_i' = random\ (l_i \sim u_i) \quad (3)$$

In other words, if a worker has three team partners and loses one of them, the upper limit of performance is one-third of the distance from the current performance to the maximum performance and the lower limit is one-third the distance from current performance to zero. For instance, if the current performance is 2/3 then the new performance will be a random number between 2/9 and 3/9. Because sorting people into separate teams may require upsetting current interdependencies, a manager might take advantage of natural synergies by attempting to keep together those who work well together. To keep these people together, the manager should divide the workers so that there is minimal interdependence disruption for higher-performing workers (Solow et al., 2002). The total disruption performance (TDP) can be measured as:

$$\text{TDP} = d_1p_1 + d_2p_2 + d_3p_3 + \cdots + d_Np_N \quad (4)$$

An alternative would be to use visual inspection of a sorted matrix to identify the best clustering, but this type of visual pattern finding becomes increasing challenging in larger or more interdependence teams. This formula helps decision maker identify splits that disconnect fewer workers and disconnect lower-performing workers. This selection orientation implicitly benefits weak performers (by keeping them with interdependent connections) and protects strong performers (by not removing them from teams that they depend on). The major reason why we would like to minimize the TDP is because a disruption to a higher performers' interdependence could be costly. The policy of protecting relationships between higher performers and their supporters is utilized in this study's interdependence-based selection orientation.

Data Collection and Analysis

The data collected from the real-world design firm are used as a source of the inputs of the ABM model for team member selection. According to the characteristics of ABM and the purpose of team member selection model, there are three data sets that are needed: (1) the complete project data from the company for a certain period; (2) the detailed information of employees including their expertise, working experience, salary, etc., and (3) the geographical area of the projects to bound the market. The data of projects and employees were collected from a small construction design firm- Yi-Hsin Engineering Design Consulting (YHEDC) located in New Taipei City in Taiwan.

The project data are collected from the 116 project proposals and contracts during 2009-2011. We spent 3 months during the end of 2012 in YHEDC in person to review the project proposals and contracts. The collected data include the items of project location, project owner, project type, start and finish time, duration, service fee, project team (who responds to do the project) and the sample form of data is shown in Table 4. The employee data for all fifteen employees involved in these projects includes working experience, expertise, and salary. The sample form of data collection for employee is shown as Table 5.

The interdependence matrix (shown in Figure 1.) was filled out by the project managers of YHEDC with face-to-face interviews. This matrix lists the relationships including who contributes to whom, and who get supports from whom among all workers in YHEDC. Other than the data collected from YHEDC, the additional project information was collected from the bidding system in the government of New Taipei City in Taiwan because YHEDC only did projects in this area. This gives us the ability to keep the ABM model as simple as possible by limiting its geographic and project scope. The distributions of collected data are shown in Figure 2. Road design and bridge design are two major project types that YHEDC focus on – more than 50% of the total projects are in these two types. Although hydraulic system design and geotechnical design cover 36% of total projects, most of these projects are associated with road and bridge design projects. Over 50% of the project design service fees are in the range of \$10,000 to \$50,000. This shows that YEHDC focuses on taking small design projects. Only 4% of the projects have service fees higher than \$100,000 and around 20% of projects have service fees from \$50,000 to \$100,000. The rest of the 21% project service fees are less than \$10,000. Considering YEHDC is a small design firm with around 15 employees and the average project design duration is 20 days, the distribution of project service fees is reasonable. There are three project managers in YHEDC and around 27% of employees have more than 20 years working experience. 46% of the employees have working experience in the range from 10 to 20 years. More than 70% of employees are senior level engineers and only 27% of employees are in entry and junior level. This shows that the project teams of YHEDC are very experienced in their professional areas. The salary range of $25,000 to $55,000 is competitive in the construction related industries in Taiwan.

Model Development

This model was developed using Netlogo (Wilensky, 1999). NetLogo is a programmable modeling environment for simulating natural and social phenomena. NetLogo is particularly well suited for modeling complex systems that develop over time. Modelers can give instructions to hundreds or thousands of agents all operating independently.

Figure 3 shows the functions of the Project Team member selection Model divided into four sections: (A) global variables input, (B) different team member selection settings, (C) a model demonstration display, and (D) a set of result displays. In Section A, one of the global variables is the number of workers, which was given an initial setting of 15. Another global variable is the economic situation, defined as a prediction about market growth or depression. A value close to 5 means that the market is better; in contrast, a value close to 1 means that the market is poor. The initial setting of 3 indicates an average economic situation. The number of simulation days can be set according to a user's target. The initial setting is 3 years, which is around 1100 days. The initial number of teams was set at 3. Section B, below the global variables on the user interface, contains buttons related to settings for team member selection orientations. There are buttons for homogenous, heterogeneous and interdependence-based team member selection. Section C is a visual market we created for the firm although the market does not contain spatial information. The model can display interactions between turtles and patches. The agents here are employees (pictured with shovels) and project managers (pictured with briefcases). Different colors of workers mean that they are on different teams. Workers of the same color are on the same team. The small squares on the background are available projects in the visual market. The different colors of the projects indicate different project costs. When workers are assigned to a project, the project color changes to pink and the workers cannot move. After the project is completed, the workers can move and search for new projects on the market. The plots in Section D shows the emergent results, including the profit earned from the model. The major function of this area is to provide an easier way to compare the differences in performance resulting from different team member selection orientations. Simple static analysis methods assess the profitability of an investment for a time span of one period.

Model Verification and Validation

We follow the guidelines of Rand and Rust (2011) for ABM verification and validation. In terms of programmatic testing, extensive unit testing was carried out to confirm that each component of the model produced desired outputs. In addition, both code walkthrough and debugging walkthrough were used. Corner cases were explored extensively to make sure that there were no bugs in the code with regards to test cases and scenarios. Finally, several specific scenarios were generated which were easily predictable, to make sure that the model behaved as expected. For example, the model was tested by the sets of scenarios including: (1) teams always outperform employees working individually; (2) teams bid more successfully for projects than employees working in isolation; (3) teams can complete larger projects than employees working isolation. In each case the model presented in this research performed as expected and so to that extent the model is verified. It is also important to validate any simulation by comparing its results to a real system (Naylor and Finger, 1967; Carson, 2002; Sargent, 2011; Rand and Rust, 2011). A curve estimation of linear regression was used to examine the fitness between the simulation results of profit earn and the collected project profit data from the Yi-Hsin design firm. The firm has been used heterogeneous team member selection as a role for their consulting teams for many years. We used the initial setting as described above at the section of model development to create a baseline of simulation based on heterogeneous team member selection orientation. The value of R^2 (0.985) indicates that the simulation results have a significant and positive correlation with the collected project profit data (shown in Figure 4). According to these comparisons, the model demonstrates validity in simulating team member selection. The following section will explore how functional diversity of teams and workers interdependence affects team performance.

Simulation for Team Member Selection Orientations

This section provides a more detailed comparison of the performance differences between the homogeneous selection, heterogeneous selection, and interdependence-based selection under different economic conditions. We first performed a sensitivity analysis for these team member selection orientations by altering the settings of the economic conditions. The economic conditions were divided into a five-part scale: 1 = very bad, 2 = bad, 3 = neutral, 4 = good, and 5 = very good. For the purpose of this model, the settings for economic conditions correspond to the number of available projects on the market. According to the data collected from the government bidding system in New Taipei City in Taiwan (which is the target market of Yi-Hsin company), the average newly available projects are three per day in a neutral economic situation. Thus for the model, setting 1 is equivalent to one new project available per day in the market; 2 is equivalent to two new projects available per day; 3 is equivalent to three new projects available projects per day; 4 is equivalent to four new projects available per day; and 5 is equivalent to five new projects available per day. The other parameters remained the same as the base condition. These five different economic conditions were examined for each of the three team member selection orientations. We ran the simulations 100 times for each of these 15 combinations of values (5 economic conditions x 3 selection orientations and averaged the results. The test results which are shown in Figure 5 indicate that the differences in profit earned in different economic contexts.

Homogeneous teams vs. Heterogeneous teams

In Figure 5, while the simulation results indicate that the difference in profit earned from homogeneous teams and heterogeneous teams is not significant, the heterogeneous teams can yield better performance when the economy is not good. The differences in performance are relatively close in extremely bad or very good conditions. The ABM is able to capture the number of projects taken by the teams, and the simulation results show that firms that utilize the heterogeneous selection take on 12% more projects than firms that use homogeneous teams in bad economic conditions. This provides evidence as to the underlying cause for the difference in performance between the two selection orientations. The deliberately assigned diversity of capabilities on each team created through the heterogeneous selection enhances each team's ability to take on a variety of projects available in the market. In contrast, while homogeneous teams can generate more capacity in a certain type of capability on each of the teams, it also limits each team's ability to take on other types of projects.

Heterogeneous teams vs. Interdependence-Based Teams

As demonstrated in the results in Figure 5, in extremely bad economic conditions, the average profit earned from teams created through interdependence-based and heterogeneous selection approaches has no significant difference. When economic conditions are better but not yet back to neutral, the interdependence-based selection is able to generate more profits than the heterogeneous selection, but not by much, as indicated by the statistically insignificant p value of 0.029 through ANOVA and Least Significance Difference (LSD) test. As explained previously, this is likely due to the absolute lack of available projects during such economic conditions. The largest gap is in the neutral condition – the teams created through the interdependence-based method were able to earn $219,456 more than the teams created through the heterogeneous selection. The trend of increased profit earned from interdependence-based selection stabilizes when the economic conditions range from good to very good.

This phenomenon indicates that interdependence-based team member selection can improve the capacity of teams as this method disrupts worker interdependencies less than traditional selection orientations, which in turn helps protect the higher performers. For example, while the heterogeneous selection orientation can increase the diversity of capabilities of teams, the net performance is often worse than optimizing worker interdependencies. These results support the argument made by Millhiser et al. (2011) that considering the interdependence of workers when building teams may be more important than primarily focusing on the individual abilities of workers. In future work, we will consider a selection orientation that attempts to maximize team diversity while at the time minimizing interdependent disruption. This could combine the best benefits of both methods.

Conclusions

This research first reviewed the team member selection related literature for project teams. Team member selection practices have focused on individual knowledge, skills, and abilities but little research has focused on examining the interdependence of team members of selection processes. A key conclusion that emerged from assessing the current literature is that project team member selection should shift away from ability-based selection to interdependence-based selection. The functional diversity of teams, interdependence between employees, and interaction with the market in different economic contexts are three major factors that affect team member selection and team performance. These factors however have not been thoroughly addressed in previous studies.

This study utilizes the NK model and DSM to capture and measure interdependence of team members. The team member's performance should be evaluated by individual contributions, giving to others, and receiving from others, which all affect a worker's total contribution to a team. The ABM developed in this study provides a framework for modeling and comparing different team member selection orientations by combining agents and the project market environment. The simulation results show that the interdependence-based selection orientation can yield better performing set of teams than traditional ability-based selection orientations. We suggest that managers should protect their higher-performing workers by minimizing interdependence disruption when building teams.

However, this research still has some limitations. First, we only use profit earned as the measurement of team performance. In reality, added-value to the clients may be more important than profit. For example, for a certain clients, shorter duration is added value, while for others, functionality, is. We may add the flexibility in the selection of outcome measures to meet different needs in future studies. Another limitation is that this model now only focuses on team member selection in local small firms. We may need to adopt other complex system theories, e.g. system of systems to explore the interdependence between different departments or different organizations in more complex market if we want to tack bigger scale problems. Third, we assume that all teams completed project without quality issues within the planned duration in order to simply our model to focus on team member selection issues. However, the situations may be more complex. For example, homogeneous teams may complete certain projects ahead of schedule, such as projects in their specific domain of expertise, freeing them up to take on more projects. Heterogeneous teams may produce better average quality of work over time resulting in greater reliability and future profitability. We may need to consider these situations to further develop this model for more accurate and optimal applications. Researchers are also recommended to collect their own data on these similar variables in the specific organizations of interest to them. They can conduct their own analyses and modify the model’s equations accordingly. Organizations can then use such further customized ABMs to examine the impact of changing the composition of teams in a risk-free artificial environment and make more informed team member selection decisions.

Implications for Practice

This research converts complexity theory into practice through an ABM. This study suggests that managers should be as aware as possible of how interdependent relationships are distributed across a cohort before they do any reorganization. These interdependencies may have as much or more effect on team performance than individual knowledge, skills, and abilities, and yet are often overlooked. The results of this study also indicate that using the homogeneous teams and the equity method for team member selection may not improve team performance by much. A manager who has worked closely and for a long time with a cohort of workers may know from observation, experience, and other types of information gathering, who works well with whom, but managers can also increase their knowledge along these fronts by conducting an internal social network analysis of their organization (Wasserman, 1994). Complex systems theory can thus guide managers in protecting the interdependencies of their most effective workers.

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Table 1. Variables of Agents (Workers)

Variable	**Description**
Education	The worker's education is divided into three major categories: graduate, college, and high school.
Working experience	The experience that a worker has from working in a specific field or occupation.
Expertise	The worker's skill or knowledge in a particular area. Since the case study in this research is a design firm that focuses on designing road construction projects, the expertise of workers include five major areas - pavement, geographical, hydraulic, structural, and environmental design.
License	Given the context, we specifically model whether workers have their professional engineer (PE) license, which is a requirement for project managers.
Salary	A salary is a form of remuneration paid periodically by an employer to an employee, the amount and frequency of which may be specified in an employment contract. In our setting, the workers' salaries are correlated with their education, working experience, expertise, and license.
Availability	This is the fraction of time that workers are available for work. Here we assume that the workers spend 8 hours per day, 22 days a month on their jobs.
Capacity	A worker's capacity is defined as the amount of work he can do. The expected capacity of workers is based on their salary. The higher the salary, the larger the capacity that is expected. In reality, the expected capacity of workers ranges from 1.6 to 2.5 times of each of their salaries.
Interdependence with other workers	The interdependence is measured and captured using the NK model and DSM. This model utilizes the DSM to capture three components of performance – individual contributions, giving to others, and receiving from others – that affect a worker's total contribution to a team.

Table 2. Variables of Projects

Variable	Description
Scope	The work that needs to be accomplished to deliver a product, service, or result with the specified feature and functions
Budget	A prediction of the costs associated with a particular project. These costs include labor, materials, and other related expenses. The project budget is often broken down into specific tasks, with task budgets assigned to each. A cost estimate is used to establish a project budget.
Duration	The duration of a project's terminal element is the number of calendar periods it takes from the time the execution of element starts to the moment it is completed.
Rate of profit	In finance, rate of return (ROR), also known as return on investment (ROI), rate of profit or sometimes just return, is the ratio of money gained or lost on an investment relative to the amount of money invested.

Table 3. Schedule of events

Build the firm
1. Create a population of projects representing opportunities in the virtual market
2. Give each project a scope, a budget, a return, and a duration
3. Create workers with their own characteristics based on the variables shown in Table 1
4. Create project teams (based on different team member selection orientations)
5. Give each team an initial set of capabilities (sum of individual capabilities)
6. Give each team a capacity (sum of individual capacity)
Team assignment
7. A team is randomly chosen to select a project
8. The team eliminates projects it cannot afford given its capacity
9. Once a project is selected, it is removed from the main choice set
10. The firm earns a return on the project it selected
11. The team’s capacity is replenished
12. Repeat events 7-9 until all teams’ capacities are full

Table 4. Sample Data Collection for Projects

Title	**Sanduo Road Construction Design**
Location	Shulin District, New Taipei City 238
Description	Road construction design for connecting Zhongzheng Road in Shulin District to Xinzhuang District
Type	Road (new construction)
Construction Duration	5/1/2009~9/30/2009
Design Duration	Basic: 30 days Detail: 40 days
Service Fee (Budget)	4,230,000 NTD (around 141,000 USD)
Service Fee (Actual)	4,000,000 NTD (around 133,000 USD)
Owner	Shulin District, New Taipei City Government
Project Manager	C. K. Chen
Engineers	B. Y. Liu, F. Y. Liu, C. B. Huang, and Z. J. Chu

Table 5. Sample Data Collection for Employees

Name	Z. P. Chen
Education	Master of Science Department of Civil Engineering, Taiwan Tech
Expertise	Hydraulic Engineering, Transportation Engineering, Landscape and Environmental Design, Construction Engineering and Management
License	Professional Engineer
Working Experience	26 years
Salary (per month)	100,000 NTD / 3,500 USD

	Employers	Title
1	Yi-Hsin Engineering Design Consulting	Project Manager
2	Taiwan Arbitration Association	Arbitrator
3	Construction and Planning Agency, Ministry of the Interior	Chief Construction Engineer
4	Construction and Planning Agency, Ministry of the Interior	Director
5	Construction and Planning Agency, Ministry of the Interior	Senior Transportation Engineer

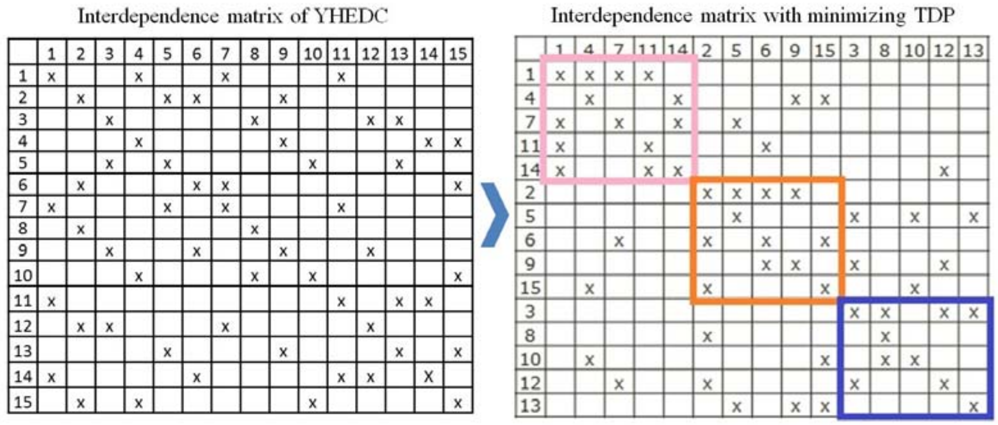

Figure 1. Workers interdependence matrices

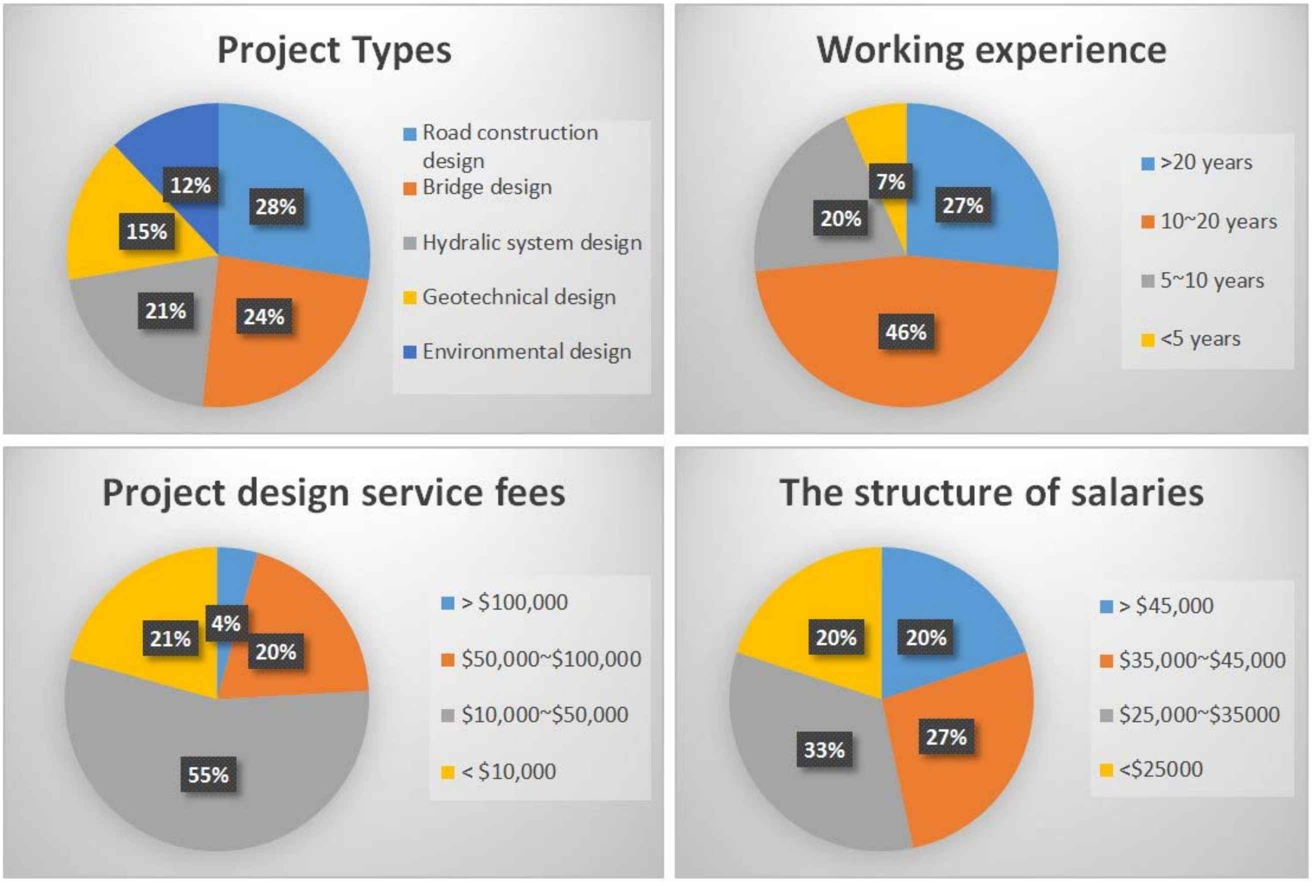

Figure 2. Distributions of collected data

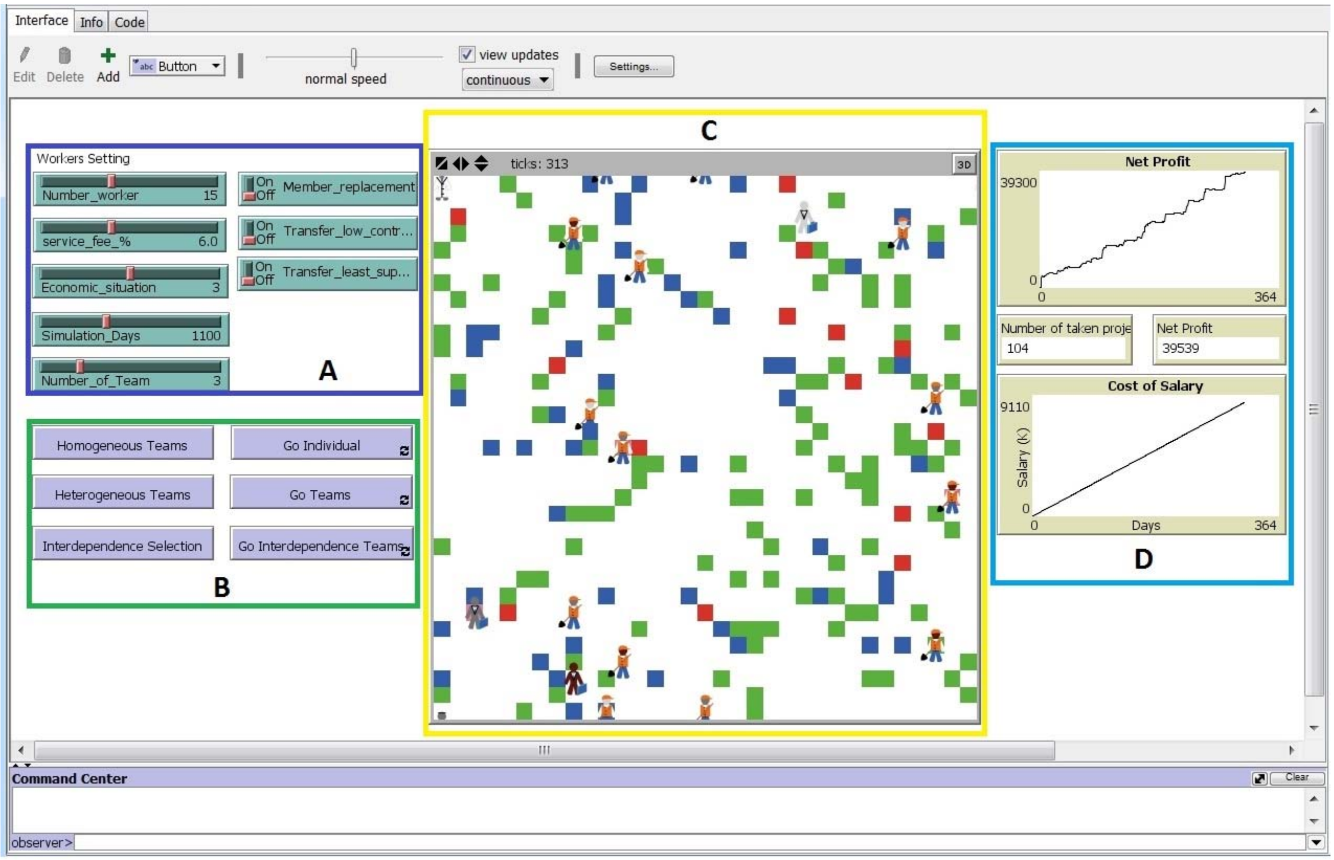

Figure 3. Project team member selection model

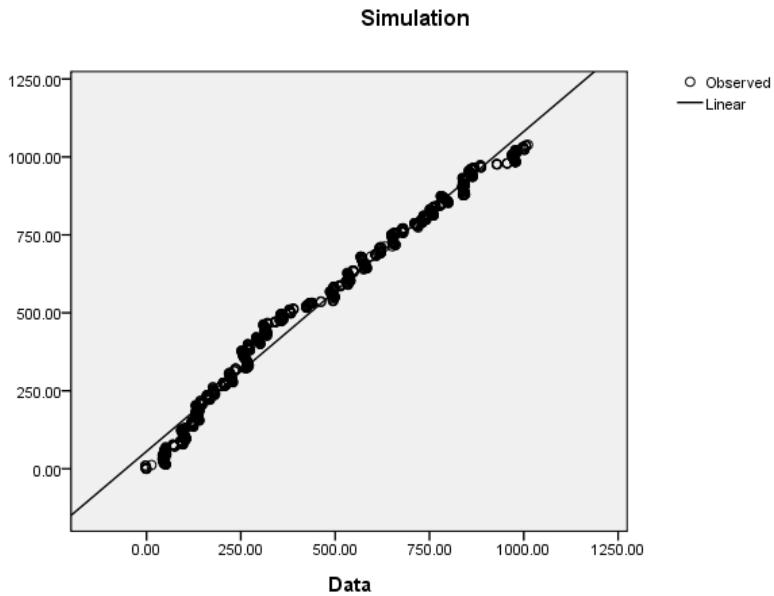

Figure 4. Curve estimation of the collected data and the simulation results

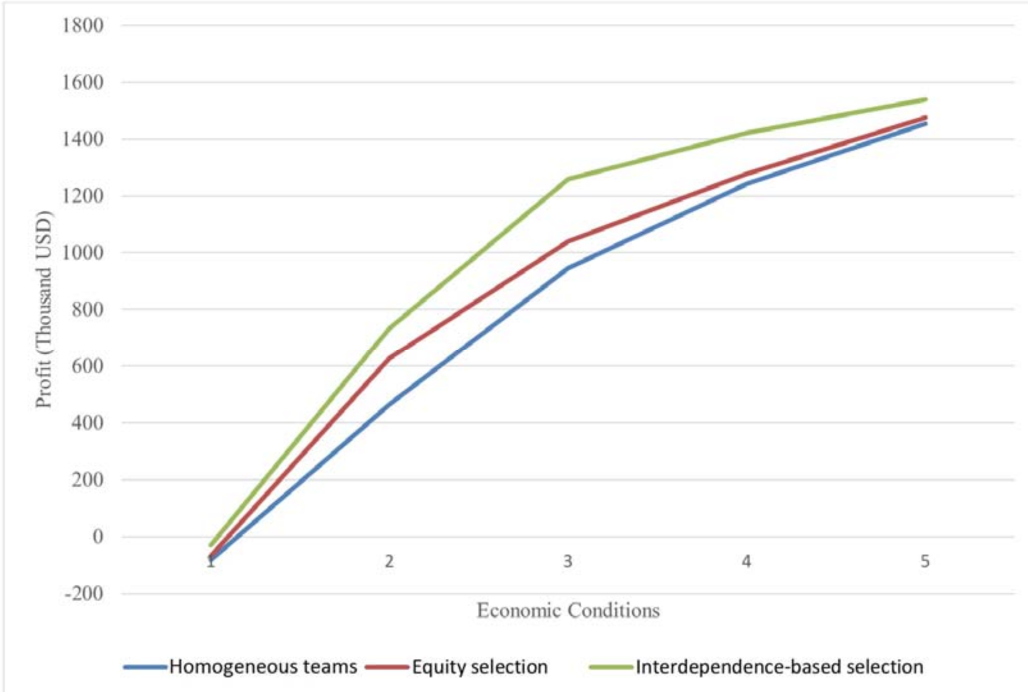

Figure 5. Comparison of different team member selection orientations under different economic conditions