

**INVESTIGATION OF INTERPERSONAL COOPERATION IN CONSTRUCTION  
PROJECT TEAMS: AN AGENT-BASED MODELING APPROACH**

By

Jing Du

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## **ABSTRACT**

### **INVESTIGATION OF INTERPERSONAL COOPERATION IN CONSTRUCTION PROJECT TEAMS: AN AGENT-BASED MODELING APPROACH**

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Construction project teams have been criticized to be incapable of delivering projects in a predictable and reliable manner. A major issue is contemporary construction practice doesn't encourage a closer cooperation among project participants. Hence as addressed by a variety of industry wide reports, the real challenge of the construction industry is to move from the current *modus operandi* to a more collaborative approach. To achieve this goal, knowledge should be advanced to fully capture the processes of cooperation in construction settings. This dissertation is intended to provide an innovative insight into the dynamics of cooperation in construction that we couldn't access before.

The basic hypothesis of this dissertation is that cooperation at the individual level among construction project team members can significantly affect team performance. In particular, diverse cooperative behaviors of project participants and corresponding micro-level processes may determine project team performance in certain scenarios. To test this hypothesis, a conceptual framework was developed to capture relevant components of interpersonal cooperation; then an ABM (Agent-Based Modeling) simulation platform, named VOICE (Virtual Organizational Imitation for Construction Enterprises) was developed for exploratory simulation experiments. VOICE allows the investigators to design an artificial construction organization just like engineers designing a bridge. It is also able to visualize project team performance by real time performance dashboards and 3D graphs.

Two case studies were conducted using VOICE to illustrate its capacity in investigating realistic cooperation related issues in construction. The first case study investigated intra-team cooperation in an estimating team. Specifically, certain cooperation related management actions -- job acquiring, coordination, and team communication -- were examined to check their influences on the estimating team performance in DBB (Design Bid Build) projects. The second case study extended the investigation to a cross-functional context where conditions become more complex. Simulation experiments were performed based on a real case between a proposal team and an engineering team in an EPC (Engineering Procurement and Construction) construction enterprise. The effects of goal congruence, as well as the implications of time pressure, task dependence and micro-management were examined based on a series of uncertainty analyses.

The findings have supported the basic hypothesis of this research that cooperation at the individual level plays a vital role in affecting construction project team performance. It was also found the investigation of cooperation in construction settings to be nontrivial because of the complex interactions of cooperative behaviors and processes. This research is anticipated to constitute a stepping stone for further investigations of cooperation in construction: for academics, it is expected that the simulation approach and findings of this research would attract more scholars' attention to the behavioral and attitudinal aspects of cooperation in construction settings; for industry, the simulation platform VOICE could be used as a decision support tool for decision makers of project management to tackle with cooperation related issues.

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*To my father*

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## TABLE OF CONTENTS

<b>LIST OF TABLES .....</b>	<b>x</b>
<b>LIST OF FIGURES.....</b>	<b>xii</b>
<b>LIST OF ABBREVIATIONS.....</b>	<b>xv</b>
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>1</b>
1.1. Background .....	1
1.2. Problem statement.....	3
1.3. Research goal and objectives .....	7
1.4. Method .....	9
1.5. Dissertation scope .....	14
1.6. Deliverables of this research .....	14
1.7. Outline of this dissertation .....	15
<b>CHAPTER 2: LITERATURE REVIEW.....</b>	<b>18</b>
2.1. Cooperation theory .....	18
2.1.1. Definition of Cooperation in construction .....	18
2.1.2. Categorization of cooperation.....	22
2.1.3. Implications of cooperation .....	23
2.1.4. Previous cooperation studies in construction area.....	25
2.2. Construction project teams.....	32
2.2.1. Definition of construction project team .....	32
2.2.2. The characteristics of construction project teams .....	34
2.2.3. Cooperation research suitable for the features of construction project team: from “top-down” to “bottom-up” .....	38
2.2.4. Performance of construction project teams.....	42
2.3. Agent Based Modeling: a bottom-up approach.....	45
2.3.1. Concepts.....	45
2.3.2. Applications of ABM.....	48
2.3.3. The rationale for using ABM in this research.....	51
2.4. Summary .....	54
<b>CHAPTER 3: A CONCEPTUAL FRAMEWORK OF INTERPERSONAL COOPERATION IN CONSTRUCTION PROJECT TEAMS .....</b>	<b>55</b>
3.1. Cooperation: a system perspective.....	55
3.2. Antecedents of interpersonal cooperation in construction project teams.....	58
3.2.1. Task characteristics .....	61
3.2.2. Individual characteristics .....	68
3.2.3. Relational behaviors.....	74
3.2.4. Organizational context .....	86
3.3. Performance indicators of construction project teams .....	91
3.3.1. Outcome performance.....	91
3.3.2. Process performance .....	93

3.4.	The conceptual framework.....	95
3.5.	Summary .....	99
<b>CHAPTER 4: A BOTTOM-UP SIMULATION MODEL OF INTERPERSONAL COOPERATION IN CONSTRUCTION PROJECT TEAMS .....</b>		<b>100</b>
4.1.	Model architecture.....	100
4.2.	Input modeling .....	101
4.3.	Process modeling.....	106
4.3.1.	Modeling individuals .....	106
4.3.2.	Modeling relational behaviors .....	110
4.3.3.	Modeling Organizational context .....	122
4.4.	Output measurement .....	129
4.4.1.	Time .....	129
4.4.2.	Quality.....	130
4.4.3.	Effectiveness .....	130
4.4.4.	Efficiency .....	131
4.4.5.	Work related pressure .....	131
4.5.	Basic assumptions of VOICE.....	131
4.6.	Developing an integral platform .....	134
4.7.	Summary .....	135
<b>CHAPTER 5: MODEL VERIFICATION AND VALIDATION .....</b>		<b>136</b>
5.1.	Verification.....	136
5.1.1.	Code debugging .....	136
5.1.2.	Logic examination .....	136
5.1.3.	Unit test.....	138
5.1.4.	Hypothetical case test .....	140
5.2.	Validation .....	143
5.2.1.	Input validation .....	144
5.2.2.	Output validation .....	151
5.3.	Summary .....	157
<b>CHAPTER 6: CASE STUDIES .....</b>		<b>159</b>
6.1.	Case Study 1: intra-team cooperation in estimating activities .....	159
6.1.1.	Case overview .....	159
6.1.2.	Model assumptions .....	161
6.1.3.	Model development .....	162
6.1.4.	Simulation results.....	165
6.1.5.	Interpretation of simulation results .....	172
6.2.	Case study 2: Inter-team cooperation in project proposal development .....	174
6.2.1.	Case overview .....	175
6.2.2.	Model assumptions .....	177
6.2.3.	Model development .....	181
6.2.4.	Simulation results.....	184
6.2.5.	Interpretation of simulation results .....	201
6.3.	Discussion .....	204

6.3.1.	General findings of simulation studies .....	204
6.3.2.	Operational recommendations .....	206
6.4.	Summary .....	208
<b>CHAPTER 7: CONCLUSIONS .....</b>		<b>209</b>
7.1.	Review of the research .....	209
7.2.	Contributions of this research .....	212
7.3.	Potential limitations of this research .....	216
7.4.	Future agenda .....	218
<b>APPENDICES.....</b>		<b>221</b>
APPENDIX 1: INFORMATION ABOUT CASE STUDY 1.....		222
APPENDIX 2: INFORMATION ABOUT CASE STUDY 2.....		232
APPENDIX 3: SAMPLE CODES .....		254
<b>REFERENCES.....</b>		<b>282</b>

## LIST OF TABLES

<b>Table 2.1</b> Definitions of Cooperation.....	21
<b>Table 2.2</b> Quadrants of cooperation enhancement practices and studies .....	32
<b>Table 2.3</b> Five types of teams; modified from (Katzenbach and Smith 1993) .....	36
<b>Table 2.4</b> The dimensions of team performance.....	43
<b>Table 2.5</b> The applications of ABM.....	49
<b>Table 3.1</b> Antecedents and determinant factors of interpersonal cooperation.....	58
<b>Table 4.1</b> Attributes of projects.....	103
<b>Table 4.2</b> Attributes of tasks.....	103
<b>Table 4.3</b> A sample table head of the online questionnaire.....	106
<b>Table 4.4</b> Attributes of actors.....	108
<b>Table 4.5</b> Relationship between tasks and relational behaviors: an example.....	110
<b>Table 4.6</b> Set of fundamental relational behaviors and specific actions.....	112
<b>Table 4.7</b> A sample survey showing individual responsibilities.....	125
<b>Table 4.8</b> Task-Actor Relation Table (TART).....	126
<b>Table 4.9</b> Basic assumptions of VOICE.....	132
<b>Table 5.1</b> Test markers and check points of functional units of VOICE.....	138
<b>Table 5.2</b> Values of attributes used in the hypothetical cases.....	141
<b>Table 5.3</b> An example of time sheet.....	146
<b>Table 6.1</b> Fitted PDFs of key variables of individuals and proposal development task.....	181
<b>Table 6.2</b> ANOVA tests under different levels of goal congruence (efficiency).....	185
<b>Table 6.3</b> ANOVA tests under different levels of goal congruence (effectiveness).....	188

<b>Table 6.4</b> ANOVA tests under different levels of goal congruence (quality).....	190
<b>Table 6.5</b> ANOVA tests under different levels of goal congruence.....	191
<b>Table 6.6</b> p-values of micro-management's influence under levels of goal congruence.....	198
<b>Table 6.7</b> p-values of micro-management's influence under levels of task dependence.....	201
<b>Table A.1</b> Task parameters of Project 1 (size=117).....	229
<b>Table A.2</b> Task parameters of Project 2 (size=115).....	230
<b>Table A.3</b> Task parameters of Project 3 (size=137).....	230

## LIST OF FIGURES

<b>Figure 1.1</b> Method of this research.....	10
<b>Figure 2.1</b> Categories of literature review.....	18
<b>Figure 2.2</b> Two approaches to enhancing cooperation in construction project teams.....	41
<b>Figure 2.3</b> The framework of construction project team performance.....	45
<b>Figure 2.4</b> The framework of an agent.....	47
<b>Figure 3.1</b> Model of organizational behavior.....	56
<b>Figure 3.2</b> Three types of task dependence.....	64
<b>Figure 3.3</b> Conceptual framework of interpersonal cooperation in construction project teams..	96
<b>Figure 3.4</b> An IPO view of the framework.....	98
<b>Figure 4.1</b> Model Architecture of VOICE.....	101
<b>Figure 4.2</b> Flowchart of the agent project.....	105
<b>Figure 4.3</b> Using Ishikawa diagram to develop the list of activities.....	106
<b>Figure 4.4</b> Flowchart of actors' behaviors (example).....	122
<b>Figure 4.5</b> An example organizational chart of a project proposal team.....	123
<b>Figure 4.6</b> Task delivery pattern in VOICE.....	127
<b>Figure 4.7</b> Information flow pattern in VOICE.....	128
<b>Figure 4.8</b> The runtime interface.....	135
<b>Figure 5.1</b> Logic errors detection by flowchart examination: example of prioritizing tasks....	137
<b>Figure 5.2</b> An illustrative project team used in model verification.....	140
<b>Figure 5.3</b> Simulation results of the first hypothetical case (examples).....	142
<b>Figure 5.4</b> Simulation results of the second hypothetical case (examples).....	142



<b>Figure 5.5</b> Surveys to collect task information.....	146
<b>Figure 5.6</b> Distribution of task duration.....	147
<b>Figure 5.7</b> Behavioral reactions to exceptions.....	151
<b>Figure 5.8</b> Distribution of work duration of the representative scenario.....	153
<b>Figure 5.9</b> Distribution of mistake percentage of the representative scenario.....	155
<b>Figure 5.10</b> Distribution of effectiveness of the representative scenario.....	156
<b>Figure 5.11</b> Distribution of number of iterations of the representative scenario.....	157
<b>Figure 6.1</b> Modeling case 1 with proposed theoretical framework .....	162
<b>Figure 6.2</b> Snapshot of the simulation (case study 1).....	164
<b>Figure 6.3</b> Real time bidding work progress (scenario 1).....	166
<b>Figure 6.4</b> Real time bidding work progress (scenario 2).....	167
<b>Figure 6.5</b> Work related stress of helpers (scenario 2).....	168
<b>Figure 6.6</b> Real time bidding work progress (scenario 3).....	170
<b>Figure 6.7</b> Accumulative effectiveness of bidding work (scenario 3).....	171
<b>Figure 6.8</b> Modeling case 2 with the proposed theoretical framework.....	180
<b>Figure 6.9</b> Snapshot of the simulation (case study 2).....	183
<b>Figure 6.10</b> Influence of time pressure on efficiency of proposal development.....	186
<b>Figure 6.11</b> Influence of time pressure on effectiveness of proposal development.....	187
<b>Figure 6.12</b> Influence of time pressure on quality of proposal development.....	189
<b>Figure 6.13</b> Influence of time pressure on averaged work pressure.....	191
<b>Figure 6.14</b> Influence of goal congruence and task dependence.....	193
<b>Figure 6.15</b> Influence of task dependence on changes to efficiency under different levels of goal congruence.....	194
<b>Figure 6.16</b> Influence of goal congruence and micro-management.....	195
<b>Figure 6.17</b> Influence of goal congruence and micro-management.....	199

<b>Figure A.1</b> Organizational chart of case study 1.....	231
<b>Figure A.2</b> Work sampling result of the face-to-face communication in a month.....	241
<b>Figure A.3</b> Fitted PDFs for input data.....	241
<b>Figure A.4</b> Organizational Chart of company Z.....	243
<b>Figure A.5</b> Influences of task dependence and goal congruence on performance of proposal development.....	244
<b>Figure A.6</b> Additional influences of task dependence on the effects of goal congruence.....	247
<b>Figure A.7</b> Influences of micro-management preference on team performance under levels of task dependence.....	248
<b>Figure A.8</b> Influences of micro-management preference on team performance under levels of task dependence.....	251

## **LIST OF ABBREVIATIONS**

ABM	Agent Based Modeling
AIA	American Institute of Architects
AON	Activity on node
ANOVA	ANalysis Of VAriance
BIM	Building Information Modeling
CII	Construction Industry Institute
DBB	Design Bid Build
EPC	Engineering Procurement Construction
IFoA	Integrated Form of Agreement for Lean Project Delivery
IPD	Integrated Project Delivery
IPO	Input Process Output
NASFA	National Association of State Facilities Administrators
OOP	Object-Oriented Programming
PBO	Project Based Organization
PDF	Probability Distribution Function
Repast	REcursive Porous Agent Simulation Toolkit
SD	System Dynamics
TART	Task-Actor Relation Table
VOICE	Virtual Organizational Imitation for Construction Enterprises
WBS	Work Breakdown Structure

## CHAPTER 1: INTRODUCTION

### 1.1. Background

The construction industry has been suffering serious performance problems, including dropping productivity (Allen 1985; Teicholz et al. 2001; Rojas and Aramvareekul 2003), time and cost overruns (Egan 1998b; Okuwoga 1998; Flyvbjerg et al. 2003; Bordat et al. 2004), frequent change orders and claims (Ren et al. 2001), and high business failure rate (Kangari 1988; Knaup and Piazza 2007). Construction project teams are criticized as not fully capable to deliver projects to the client in a reliable and predictable manner (Egan 2002). A widely accepted explanation of these performance issues is that project participants are unable to work together effectively (Arditi et al. 2000; Cheung et al. 2003; Phua and Rowlinson 2004; Anvuur and Kumaraswamy 2007). Contemporary construction system and project management approaches don't encourage effective cooperation between project participants (Cheung et al. 2003; Chen and Tien 2007; Kang et al. 2007; Son and Rojas 2010). Hence the real challenge of the industry is to move from the current *modus operandi* towards collaborative approaches (Latham 1994; Egan 1998; Bourn 2001; Egan 2002; Kang et al. 2007). Achieving this goal requires deeper insight into the nature and implications of cooperation in the construction context.

Any construction project is a temporary coalition of a number of groups (Shirazi et al. 1996; Dubois and Gadde 2002; Bouchlaghem et al. 2004). The project team members hold divergent interests and foci (Winch 2003; Bouchlaghem et al. 2004; Ruikar et al. 2007). Their success is defined by achieving performance metrics for the individual

organization instead of for the collective project performance (Cornick and Mather 1999). This situation creates a “fragmented” atmosphere in construction project teams (Baiden et al. 2006), which in turn leads to a “blame culture” where team members seek to minimize their responsibility for poor performance, rather than working together towards cooperation (Baiden et al. 2006). It is thus difficult for a project team to promote the progress of the work through concerted actions and implementation of decisions (Hackman 1990; Devine et al. 1999; Grant 2007). As highlighted by Phua and Rowlinson (2004), cooperation between employees in construction project teams remains a serious issue that needs attention.

Building on surveys and interview studies, the benefits of improved cooperation in the construction context have been well recognized -- Better cooperation can break down barriers (Albanese 1994), foster innovation (Dulaimi et al. 2002; Dulaimi et al. 2003), exert positive implications for project performance, creativity and learning (Dubois and Gadde 2002; Dorée and Holmen 2004; Phua and Rowlinson 2004) and, promote psychosocial outcomes for employees (Pinto et al. 1993b).

In recognition of the importance of cooperation in construction, a number of “Integration Toolkits” have been proposed and applied in the industry to enhance the cooperation among team members, such as concurrent engineering (Love et al. 1998), partnering (Bresnen and Marshall 2000b), project strategic alliance (Li et al. 2001), integrated project delivery (Eckblad et al. 2007), and also a great interest in collaborative tools and

techniques, such as web based project management (Nitithamyong and Skibniewski 2004) and building information modeling (Azhar et al. 2008).

Despite the distinctness of these approaches, they are all ultimately intended to remove the obstacles between project participants, increase the transparency, enhance the level of trust, and create an integrated and collaborative project team effort for project delivery (Thomas and Thomas 2005; Gudgel 2008; NASFA et al. 2010).

## **1.2. Problem statement**

Despite the attempts to enhance cooperation in the construction industry, there is still a lack of precise knowledge of the nature and implications of cooperation in construction project teams, keeping cooperation research in construction somewhat of a “*black box*” (Anvuur 2008). Fundamental questions about cooperation in construction project teams remain unanswered, such as: what factors facilitate/hinder the cooperation in construction project teams? To what extent do they do so? Are the effects linear (as described in certain studies, e.g., Cheung 2003; Phua and Rowlinson 2004; Anvuur 2008), or nonlinear (as described by Thomsen 2005)? Bresnen and Marshall (2000b) asserted that any contribution leading to a better understanding of the cooperation concept that unifies/integrates the multiple theoretical perspectives in construction project teams would be a significant contribution to knowledge. It should be noted that developing a precise knowledge of the cooperation in construction is a difficult (if not impossible) task, which requires long-term research efforts by the academia. This dissertation only moves one step

closer to provide a unique insight into this theme. Specifically, it addresses four major theoretical gaps in current cooperation studies in construction.

First, there is a lack of efforts by construction academics and industry to investigate cooperation at the individual level in construction project teams, despite its evident importance for successful project delivery (Fisher and Green 2001). A survey reported by Phua and Rowlinson (2004) revealed that “*cooperation between the colleagues in a construction firm*” exerts a much stronger influence (coefficient=0.22) on the construction project performance than does “*cooperation between construction firms*” (coefficient=0.02). In other words, interpersonal cooperation is the fundamental element of cooperation in construction project teams. However, the construction literature has paid too much attention to the cooperation issues between project organizations, and tended to ignore the need to differentiate cooperation at an individual level from that at an organizational level (Eckblad et al. 2007). Most construction literature simply refers to “*cooperation of construction project teams*” as “*inter-organizational integration*” (Cheng et al. 2001; Lam et al. 2001; Welling and Kamann 2001; WL 2004), or as part of “*partnering between construction firms*” (Bresnen and Marshall 2000b; Wood et al. 2002; Naoum 2003). Only a few research efforts in construction have highlighted the need to investigate individual or interpersonal cooperation and their arguments haven been conflicting (Phua and Rowlinson 2004; Anvuur and Kumaraswamy 2007; Anvuur 2008; Son and Rojas 2010). Thus investigating individual-level cooperation in construction

project teams is needed to augment the body of knowledge regarding cooperation in the construction industry.

Second, there is an urgent need to investigate the behavioral and attitudinal aspects of cooperation in construction project teams, considering the insufficiency of industrial emphasis on searching for contractual, strategic and technical remedies (Son and Rojas 2010). Attempts to foster cooperation in construction project teams have mainly focused on improving product delivery processes and strategic alliance to ensure the cooperation among different disciplines in construction projects (Cheng et al. 2001; Lam et al. 2001; Welling and Kamann 2001; WL 2004; Baiden et al. 2006). These attempts have not completely reached the anticipated success. A likely explanation is *“they are frequently superimposed onto environments where adversarial cultures and attitudes still exist”* (Moore and Dainty 2001). Project team members are mostly affected by behavioral, social and cultural factors rather than simply the institutional and contractual factors (Son and Rojas 2010). This highlights the importance of looking into the psychosocial perspectives of cooperation in construction project teams in order to address the cooperation issues in the construction industry (Anvuur 2008).

Third, the evidence of relationship between cooperation and construction project team performance has remained anecdotal, subjective and piecemeal, which undermines the industrial support on enhancing cooperation for better performance (Anvuur 2008). Existing literature findings (Cheng et al. 2001; Lam et al. 2001; Welling and Kamann



2001) are usually based on regional surveys which occasionally contradict with each other (Phua and Rowlinson 2004). Although research on organizations in other industrial settings demonstrates a strong positive link between individuals' cooperative behaviors and organizational/team effectiveness (Ruekert and Walker Jr 1987a; Souder 1988; Hise et al. 1990; Motowidlo and Van Scotter 1994; Pfeffer 1994; Podsakoff and MacKenzie 1997; Hoegl et al. 2004; Podsakoff et al. 2009), evidence in the construction industry is still lacking (Phua and Rowlinson 2004). This situation undermines the industrial understanding of and support for enhancing cooperation for dealing with performance issues in the construction industry. It's worth noting that, solid evidence of the relationship between cooperation and construction project teams requires long term investigation with a comprehensive body of samples. This dissertation only aims to provide a systematic way (and probably an easier way) for such investigations.

Last, existing research efforts aim to provide a remedy for cooperation issues in the construction industry through "top-down" changes such as partnering (Malone and Crowston 1990; Bresnen and Marshall 2000b; Wood et al. 2002; Naoum 2003). Such a "top-down" approach has proven insufficient to capture the real needs of enhancing cooperation in construction settings (Moore and Dainty 2001). Based on an analysis of the natural features of construction project teams, this study proposes that a "bottom-up" approach, i.e., emphasizing the transition from a local diversity of cooperation processes and behaviors to global performance of project teams, is a good fit for cooperation research in the construction context. In fact, certain cooperation enhancement approaches

in construction, such as Target Value Design (TVD), are effective because they allow bottom-up changes. Seemingly a top-down approach, TVD actually works by encouraging the cooperation among project participants in a bottom-up manner (Macomber et al. 2007). Therefore, it is expected that through enhancing interpersonal cooperation, especially by behavioral changes of team members, insight into cooperation issues in construction project teams will be advanced.

In a short, the limitations addressed in this dissertation can be grouped into four clusters: (1) A lack of effort to investigate cooperation at the individual level in construction; (2) A lack of attention to the behavioral and attitudinal aspects of cooperation in construction; (3) A lack of a systematic approach to investigate the relationship between cooperation and construction project team performance; and (4) A lack of bottom-up research methods to capture the complexity of the studied theme. Based on these problems, the goal and objectives of this research are stated.

### **1.3. Research goal and objectives**

The main goal of this research is to investigate interpersonal cooperation in construction project teams, with a focus on the transition from local dynamics of individual behaviors and micro cooperation processes to global performance of project teams. Specifically, the main aim is to develop a conceptual framework and simulation model that allows a rigorous theory-based investigation of the micro-level behavioral and attitudinal factors that shape local interpersonal cooperation processes in construction project teams, and

their impacts on team performance. This will be achieved through the following specific objectives:

**A. To create a conceptual framework for investigating interpersonal cooperation in construction project teams**

Questions: What is the definition of interpersonal cooperation? What are the constructs of interpersonal cooperation? What are the implications of interpersonal cooperation? What are the measurements of construction project team performance? What are the lessons learned from previous studies?

Significance: Establish a rational and solid conceptual foundation for the current study.

**B. To develop a bottom-up simulation model for investigating interpersonal cooperation in construction project teams**

Questions: What aspects and factors should be included in the proposed simulation model? How should interpersonal cooperation be represented in the conceptual model's architecture? What is the level of detail for such representation? How can team performance indicators be formulated? How will the model's development be realized? How will the model be verified and validated?

Significance: A comprehensive, concise, accurate, and verified simulation model forms the basis for further analysis.

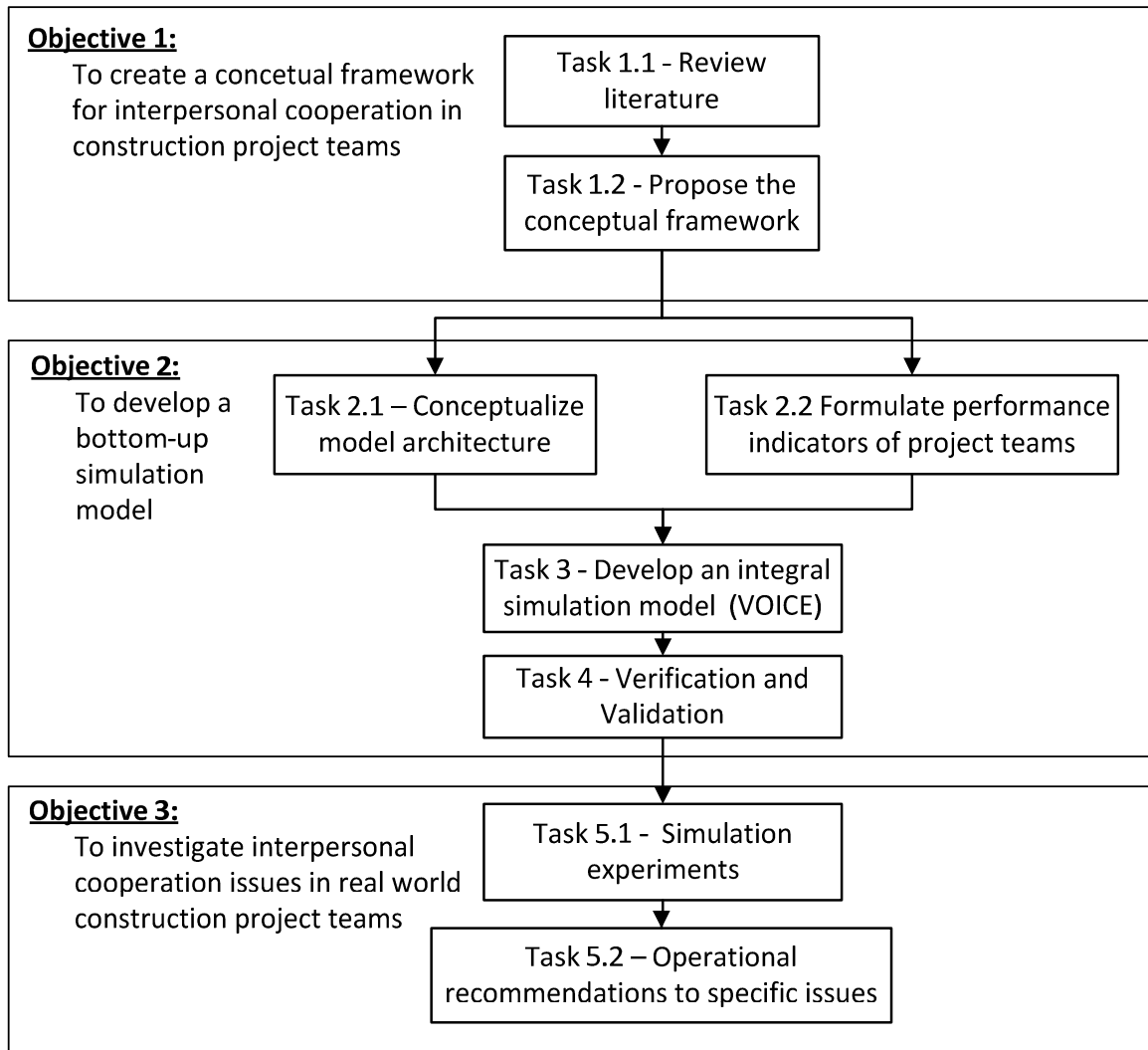
### **C. To investigate interpersonal cooperation issues in real world construction project teams**

Questions: What are the representative cooperation related issues in real world construction project teams? How can the conceptual framework and simulation model be applied to investigate these issues? How can the simulation model be tailored for specific scenarios? Can recommendations be given to improve construction project team performance through exploratory simulations based on the simulation model?

Significance: Experiments based on exploratory simulations constitute the basis for creating transformative knowledge of interpersonal cooperation in construction settings.

#### **1.4. Method**

Figure 1.1 demonstrates the specific tasks undertaken in this research to achieve its three objectives. This section briefly describes these tasks as the method of this research.



**Figure 1.1** Method of this research

### **Task 1: Reviewing literature and proposing a conceptual framework**

This step identified the gaps in current studies, framed foci in this research, and built a solid conceptual framework for interpersonal cooperation in construction. Three subtasks were conducted to form the point of departure for the entire research: (1) To identify the gaps of current literature, and conceptualize the research problems about interpersonal

cooperation in construction project teams that will be investigated in this research; (2) To survey a comprehensive body of literature related to the object of study and theoretical base, including the definition and natural features of construction project teams, cooperation theory (definition, constructs and influences), team performance (definition and measurements), and ABM with its concepts, features, applications and rationale in the proposed study; and (3) To propose a conceptual framework based on the comprehensive literature review for investigating interpersonal cooperation and team performance in construction project teams. The proposed framework has demonstrated the conceptual connection between the components of interpersonal cooperation and the measurements of team performance and thus constituted the foundation of the simulation model.

## **Task 2: Conceptualizing model architecture and formulating performance indicators of construction project teams**

Conceptual model architecture served as a transition from a conceptual framework to an executable simulation model in this research. This step developed a model architecture to represent interpersonal cooperation in construction project teams. In particular, interpersonal cooperation was represented as a set of attributes and model rules by the following steps: (1) model variables of interpersonal cooperation: variables were defined as the attributes, status and specifications of every interpersonal cooperation construct (e.g., competence of individuals or task dependence which can affect interpersonal cooperation) with clear definitions, units and value ranges; (2) model behavioral rules of

interpersonal cooperation: the model rules were represented as cooperative behaviors and logic relationships among different cooperation constructs which were established based on the literature and case studies; and (3) build an overall model architecture: the model architecture was finally established to capture attributes and methods derived from interpersonal cooperation representations.

Notably, the model outputs also needed to be represented as part of the model architecture, i.e., key indicators of construction project team performance. This study first examined the major construction literature to identify the team performance measurements applied in the industry. Then these findings were summarized to provide a framework for measuring construction project team performance. Finally specific measures of individual indicators were defined and formulated according to the requirements of model development. The representation of interpersonal cooperation and project team performance established the foundation of the model development.

### **Task 3: Developing an Agent Based Model for interpersonal cooperation in construction project teams**

An Agent Based Modeling (ABM) simulation platform (Virtual Organizational Imitation for Construction Enterprises, VOICE) was developed based on the conceptual model's architecture. The following process was utilized to realize the simulation platform: (1) schematic design: design and define the basic agents, structures and behaviors, and select the basic algorithms; (2) prototyping: create an outline model that includes the most basic

agents and related behaviors to test the feasibility of the proposed architecture; (3) designing agents: specialize and revise agents' properties and behaviors, together with related algorithms used in the prototype, to make agents close to reality; and (4) designing the agent environment: specify the agent's world, which is the relationship between agents in terms of organizational structures.

#### **Task 4: Model verification and validation**

A hybrid method was utilized to verify the developed model, with subtasks including automated error detection, logic examination, unit testing and hypothetical cases. After that, the developed model was validated with a twofold procedure following Sargent (1999), including input validation which focuses on the key variables and micro-level behavioral rules used in the simulation model and output validation which provided certain level of justifications of the reasonableness of the outcomes generated by the model.

#### **Task 5: Simulation experiments and operational recommendations to specific construction related cooperation issues**

To illustrate the usefulness of the proposed model in investigating interpersonal cooperation in construction project teams, a series of exploratory simulations were performed using VOICE to examine team performance under different setups and initial conditions of interpersonal cooperation. In each simulation experiment, organizational context, relational behaviors of participants, work and other components of the



interpersonal cooperation are set to different values, and the results are recorded and analyzed using uncertainty analysis. Although uncertainty analysis is always used interchangeably with sensitivity analysis, it is mainly interested in the viability in the simulation outputs while sensitivity analysis also investigates the quantitative correlation between inputs and outputs (Smith and Smith 2007). Given the scope of case studies in this dissertation, uncertainty analysis was used. Finally, operation recommendations were developed for improving construction project team performance in studied cases through certain strategies for interpersonal cooperation.

### **1.5. Dissertation scope**

The main focus of this dissertation is the cooperative behaviors and processes pertaining to the construction management activities (e.g., proposal development) at the home office. Cooperation related to construction field operations (e.g., steel erection) has not been addressed due to the scope of this research. In addition, only project task related cooperative behaviors and processes have been investigated in this research. Other influential factors such as work-life balance or learning are not within the scope of this research since they are the main foci of psychosocial studies (Frosh and Baraitser 2008).

### **1.6. Deliverables of this research**

There are two main deliverables of this research. First, this research developed a conceptual framework for investigating interpersonal cooperation in construction project teams. Particularly, the proposed framework captures the key points of interpersonal

cooperation in the construction context, inducing the technical, institutional and behavioral aspects that are believed critical for the performance of construction projects and project teamwork. The framework highlights elements or antecedents of interpersonal cooperation, and captures the transition from interpersonal cooperation elements to ultimate construction project team performance.

Second, another outcome of this research is VOICE, a simulation model to investigate real-world cooperation issues in construction project teams. VOICE was built on the basis of the proposed conceptual framework following the modeling principals of ABM. VOICE is able to reproduce how construction projects are divided into tasks and processed by roles of a project team such as president, project managers and staff members. The analytical function of VOICE (e.g., uncertainty analysis) allows exploratory experiments for examining and quantifying the influences of different interpersonal cooperation elements on construction project team performance.

## **1.7. Outline of this dissertation**

The remainder of this dissertation is organized as follows:

Chapter 2 discusses the theoretical foundation of the research work, including a brief discussion of cooperation theory, an overview of previous cooperation studies in construction academics, the nature and evaluation of construction project teams, and the rationale of applying ABM in this research.

Chapter 3 extends the review of literature on cooperation theory and construction teams to build a conceptual framework specific for interpersonal cooperation in construction project teams. Major constructs of interpersonal cooperation are proposed; each construct is discussed in detail by summarizing theories pertaining to the corresponding theme.

Chapter 4 builds a simulation platform (Virtual Organizational Imitation for Construction Enterprises, VOICE) on the basis of the proposed conceptual framework, for investigating interpersonal cooperation and its implications in construction project teams. This chapter provides the computing details and research strategies of each critical model component.

Chapter 5 introduces the verification and validation (V & V) of VOICE. A hybrid methodology was employed to determine the validity of VOICE, including surveys, document studies, structured interviews, and hypothetical case simulation experiments. A testimonial attests that the V & V approaches used are good enough to ensure the confidence of the following analyses based on VOICE.

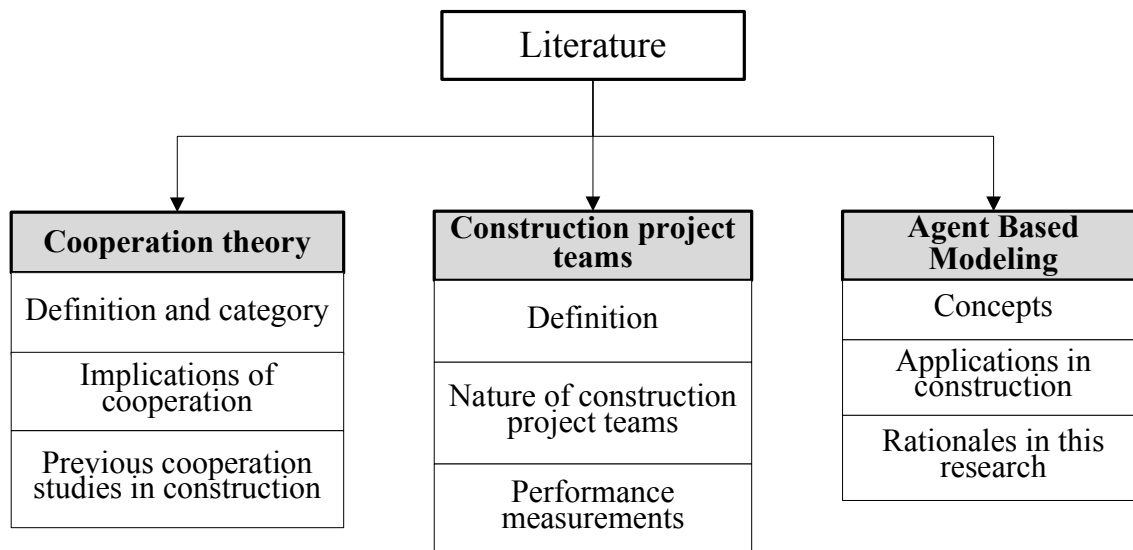
Chapter 6 introduces two case studies to demonstrate the usefulness of VOICE. The first case study focuses on how cooperative behaviors and institutional arrangement between members of an estimating team impact management actions and team performance in typical Design Bid Build (DBB) projects. The second case study investigates the role of goal congruence in the cooperation between members of different teams during project proposal development of EPC projects (Engineering, Procurement and Construction). Causes, behaviors and consequences of goal incongruence are examined using VOICE

based on an in-depth case study to an American mega-million-dollar construction enterprise. Based on an interpretation of the simulation results of the two case studies, several operational recommendations are given to improve project team performance through cooperation enhancement.

Chapter 7 reviews the whole work and provides a constructive evaluation of this research. It identifies common and distinctive features of interpersonal cooperation in different construction settings. The concluding chapter also presents on the limitations and the ways to address them in the future.

## CHAPTER 2: LITERATURE REVIEW

This chapter reviews the literature in construction studies and other relevant areas to identify the gaps of current studies and conceptualize the focus problems in this research. Three categories of literature are covered including cooperation theory, construction project teams and Agent Based Modeling (Figure 2.1).



**Figure 2.1** Categories of literature review

### 2.1. Cooperation theory

#### 2.1.1. Definition of Cooperation in construction

*Cooperation* has no explicit meaning in the construction literature (Anvuur 2008). Rather, it is always used under notions of *coordination* or *partnering* (Anvuur 2008), and is often confused with *collaboration* (Pocock and Kim 1997; De Saram and Ahmed 2001a; Cheung et al. 2003; Naoum 2003; Phua and Rowlinson 2004; Jha and Iyer 2006). The majority of construction literature seems to use *cooperation* and other relevant terms

interchangeably (Bresnen and Marshall 2000a; Vaaland 2004; Eriksson and Laan 2007; Eriksson and Pesämaa 2007). This variability in terminology clouds the understanding of the basic concept and makes the integration of the contributions of different researches impossible. To clarify the distinction, relevant concepts are compared below.

*Coordination* is the management of the dependencies between activities (Bresnen and Marshall 2000a; Becerik 2004; Cicmil and Marshall 2005), the “*extra activities required to maintain consistency within a work product or to manage dependencies within the workflow*” (Malone and Crowston 1994). It also refers to additional information processing when multiple actors work toward a larger goal (Curtis 1989).

*Partnering* is a generic management approach to align project goals or strategies (Malone and Crowston 1990). It is a way to achieve an optimum relationship between project participants (Love et al. 2002; Bayliss et al. 2004), either in particular projects or as a long term “strategic alliances” (Cowan 1992).

*Collaboration* is the long-term alignment and integration between organizations (Cheung et al. 2003). It signifies a higher degree of integration in the partnering relationship (Hamel et al. 1989; Kanter 1994; Thompson and Sanders 1998; Love et al. 2002), and is always conceptualized as opposite to competition in inter-organizational relationships (Thompson and Sanders 1998).

*Cooperation* is mostly defined as individual behaviors to achieve mutual goals (Hamel et al. 1989; Thompson and Sanders 1998); or the interpersonal interactions when different

functional units work together for overall organizational tasks (Johnson 1975). It reflects the willful contribution of team members to the achievement of shared goals (Tjosvold 1988; Pinto and Pinto 1990).

From the above discussion, it is clear that cooperation is very different from other concepts. First, *cooperation* is mainly a concept about interpersonal interactions to achieve a mutual goal, while collaboration or partnering is a term used in illustrating the integration or strategic alliance between organizations. Second, the scope of *cooperation* could be either inter- or intra-organization, while collaboration or partnering tends to be across, rather than within, organizational boundaries. Third, *cooperation* emphasizes the pattern of interactions and social relations, while other concepts (e.g., coordination) are mainly about the management activities. Table 2.1 summarizes definitions given by the literature with the same inference. Accordingly, in this research cooperation in the construction context is defined as: *A behavior toward the accomplishment of the shared construction project goals of all project parties, and also a process that underlines the pattern of interactions among project participants.*

The functionality of both the behavioral and process perspectives of cooperation are supported by the literature (Wagner III 1995; Dukerich et al. 2002; Phua 2004), and therefore both perspectives are central foci of this research. In construction, cooperative behavior often involves “problem-solving, creating new value together or striving for win-win scenarios” (Chen et al. 1998), while the process perspective implies the dynamic

developmental approach to cooperation (Anvuur 2008). The basic premise of this study is that understanding both perspectives can provide better insight into the formation and consequences of cooperation. As the readers will find in chapter 4, the simulation model developed in this research captures cooperative behaviors as the actions of team members, and cooperative processes as how project tasks are assigned, processed, coordinated, delivered and submitted in a project team.

**Table 2.1** Definitions of Cooperation

Literature	Terminology	Definition
(Schermerhorn Jr 1975)	Cooperation	“The coordination of behaviors among individuals to achieve mutual goals”
(Johnson 1975)	Cross-functional cooperation	“The quality of task and interpersonal relations when different functional areas work to accomplish organizational tasks together”
(Pinto and Pinto 1990)	Cross-functional cooperation	“Joint behavior toward some goal of common interest. In context of construction projects, it is conceptualized as the degree, extent and nature of interpersonal relationships among project team members from multiple functional areas”
(Pinto et al. 1993b)	Cooperative inter-organizational relationships	“Socially contrived mechanisms for collective action, which are continually shaped and restructured by actions and symbolic interpretations of the parties involved”
(Ring and Van de Ven 1994)	Cooperation	“The willful contribution of personal effort to the completion of interdependent jobs”
(Wagner III 1995)	Cooperation	“Individuals, groups and organizations come together to interact and form psychological relationships for mutual gain or benefit”
(Smith et al. 1995)	Inter-organizational cooperation	“The presence of deliberate relations between otherwise autonomous organizations for the joint accomplishment of individual



**Table 2.1** Cont'd

Literature	Terminology	Definition
		operating goals”
(Smith et al. 1995)	Cooperation	“Refers to whether or not people act to promote the goals of the group”
(Tyler and Blader 2000)	Cooperation	“Cooperation means people working together on the basis of common interests. It is the most effective behavior to adopt in all human relationships”
(Bennett 2000)	Cooperation	“The act of working together to one end”
(Mead 2003)	Cooperation	Refers to “where individuals acting together benefit more than they would alone”

### **2.1.2. Categorization of cooperation**

Cooperation research, as Smith et al. (1995) highlighted in an extensive literature review, is “rich in theory and diverse in its academic roots”. A rich body of literature discusses the contents of cooperation (Terhune 1970; Schermerhorn Jr 1975; Axelrod and Hamilton 1981; Schmitt 1984; Pinto et al. 1993b; Chatman and Barsade 1995; Smith et al. 1995; Wagner III 1995; Chen et al. 1998; Tyler and Blader 2000; Mead 2003; Roberts 2005; Bewsey and McCord 2006; Anvuur 2008). However, because of the lack of a generic framework, the literature always gives different or even contradicting conclusions (Yilmaz and Hunt 2001). In order to propose a generic framework that incorporates all theoretical perspectives, the first step is to revisit the theoretical traditions of cooperation research.

The literature has recognized cooperation as a multifold concept (Rabbie 1991; Smith et al. 1995; Tyler and Blader 2003; Anvuur 2008). Oriented from Behavioral Interaction Model,

Rabbie (1991) found that two kinds of cooperation can be distinguished, i.e., instrumental cooperation and social cooperation. In instrumental cooperation, people cooperate to attain economic or other tangible outcomes; whereas in social cooperation (or relational cooperation), the aim is to achieve a mutually satisfying relationship with others so that one can be recognized as a positive social identity. As a result, cooperation can be grouped into two categories: formal cooperation that stems from the formal hierarchy, and informal cooperation rooted in a belief that others will faithfully contribute to the group (Smith et al. 1995). This idea has recently been revisited by Anvuur (2008) who described two kinds of cooperation: obligatory cooperation and voluntary cooperation. Obligatory cooperation is triggered by “extrinsic factors” such as contractual obligations and formal structures of job design. Voluntary cooperation is motivated by “internal factors”, i.e., a positive sense of “self-identity” (Tajfel 1982). This research mainly focuses on obligatory cooperation instead of voluntary cooperation.

### **2.1.3. Implications of cooperation**

The benefits gained from better cooperation have been documented by the literature (Albanese 1994; Dulaimi et al. 2002; Kadefors 2004; Phua and Rowlinson 2004). One most apparent effect of cooperation is it can break down barriers and facilitate the building of more stable and long-lasting relationship among different teams (Albanese 1994; Chan et al. 2003; Chan et al. 2009). As a result, enhanced cooperation improves the level of trust and commitment between project team members (Morgan and Hunt 1994; Kadefors 2004; Shek-Pui Wong and Cheung 2004; van Marrewijk 2005). Recent findings

also indicate that cooperation may foster innovation in construction organizations (Dubois and Gadde 2002; Dulaimi et al. 2002; Dulaimi et al. 2003; Miozzo and Dewick 2004).

This research paid special attention to the importance of cooperation in enhancing project performance and success (Latham 1994; Bennett and Jayes 1995; Barlow et al. 1997; Bresnen and Marshall 2000b; Phua and Rowlinson 2004). Phua and Rowlinson (2004) conducted extensive interviews and a survey of construction firms in Hong Kong to identify the impacts of different levels of cooperation on construction success. Results showed that cooperation between firms as well as between employees in one company can significantly affect the success of both consulting and contracting firms. A critical literature review regarding the UK construction industry reached a similar conclusion (Fisher and Green 2001). Furthermore, these findings are consistent with a wider range of literature (Latham 1994; Bennett and Jayes 1995; Barlow et al. 1997; Bresnen and Marshall 2000b). Meissner et al. (2005) found closer cooperation between engineers in project teams is the basis of high quality projects, short development duration and a minimum of investment costs. Chen et al. (2004) found the establishment of a conflict resolution strategy to be a critical success factor for partnering projects. However, as Phua and Rowlinson (2004) and Anvuur (2008) have commented, the relationship between cooperation and project performance has rarely been empirically tested; the conclusions are mostly based on piecemeal and anecdotal evidence (Barlow et al. 1997; Bresnen and Marshall 2000b; Fisher and Green 2001).

#### **2.1.4. Previous cooperation studies in the construction literature**

Cooperation research in the construction domain could be grouped into two categories: “instrumental research”, i.e., those focusing on procedural, contractual, strategic and technical remedies towards better cooperation, and “behavioral research”, i.e., studies on the behavioral and attitudinal perspectives of cooperation.

##### *2.1.4.1 Instrumental remedies towards better cooperation*

Contemporary industrial remedies to cooperation in construction project teams show a strong emphasis on procedural, contractual, strategic arrangements and collaborative techniques and tools. Among the emerging integration approaches, one of the earliest topics that has been investigated is partnering, a general management approach to line up project goals and strategies (Bresnen and Marshall 2000; Wood et al. 2002; Naoum 2003). It could be applied to enhance relationships between contracting parties, either in particular project partnerships or as “long term strategic alliances” (Cowan 1992). In partnering projects, all project parties are required to transform their businesses in terms of relationships, processes, communications and leadership (CII, 1989, 1991). Despite the difference between approaches, they still rely on a pragmatic and instrumentalist perspective which states that in order to achieve a partnering arrangement, patterning tools, techniques, and procedures for organizations to follow should be established (Bresnen and Marshall 2000).

Another stream of thought to align the efforts of project parties is by adopting a Linguistic Action Perspective (LAP) in construction management (Koskela and Howell 2002). The traditional dispatching model of construction management assumes that project tasks, once authorized, can be automatically understood, started and finished as planned (Koskela and Howell 2008). Thus construction management simply refers to a strong casual connection between the actions and the outcomes. However, as Flores found (1981), management is indeed “a process of openness, listening, and eliciting commitments, which includes concern for the articulation and activation of the network of commitments, primarily produced through promises and requests”. As a result, LAP has been proposed to highlight the need that project tasks should be “coordinated through making and keeping commitments, rather than by central control” (Koskela and Howell 2008). At present, LAP essentially serves as the theoretical foundation of a variety of successful Lean Construction practices such as Last Planner System (LPS) (Macomber and Howell 2003). For example, a core of the successful lookahead scheduling in LPS is a commitment cycle beginning with “a request, followed by a promise, performance and declaration of completion” (Macomber and Howell 2003). In this sense, LPS encourages cooperation because it articulates and activates a network of reliable commitments so people can organize and assemble the efforts to deliver the promise of the project while acting in their own interests (Macomber and Howell 2003).

Recently, Integrated Project Delivery (IPD) has also received increasing attention as a philosophy and approach to encourage cooperation among project participants (Bishop

2008). IPD builds on a variety of contractual and economic principles, including early involvement of project participants, collective decision making, shared project criteria, shared financial risk, liability waivers, fiscal transparency between project partners, and intensified design (NASFA et al. 2010). From a wider context of economic models of contracting, IPD actually reflects the principal of relational contracting (Matthews and Howell 2005), which refers to “a transaction mechanism that seeks to give explicit recognition to the commercial relationship between project parties” (Colledge 2005). Relational contracting views contracts as relations rather than as discrete transactions (Macneil 1973). It captures a wider social and economic context (Cullen et al. 2005), and focuses on building long term trust and relationship among project parties (Matthews and Howell 2005; Sakal 2005). In contrast, traditional construction contracting method encourages local optimization behaviors which lead to adversarial and competitive relationship (Colledge 2005; Matthews and Howell 2005).

In fact, construction activities are highly specialized, involving multiple parties with durations for different commencement and completion, which necessitates relational approaches even on the simplest of building project (Colledge 2005). Therefore it is not surprising that relational contracting approaches have been successfully implemented in many construction projects (Cullen et al. 2005; Gerrard 2005; Lichtig 2005). At present, a number of national standard construction contract formats have been developed based on relational contracting, including “Standard Form Multi-Party Agreement for Integrated Project Delivery” (AIA C191–2009), “General Conditions of the Contract for Integrated

Project Delivery” (AIA A295–2008), and “Integrated Form of Agreement for Lean Project Delivery” (IFoA). The relational contracting formats reflect a tendency of the industry to remove the obstacles of cooperation and innovation by aligning the interests of all project participants (Matthews and Howell 2005).

The literature also has shown a growing interest in collaborative techniques and tools, especially Building Information Modeling (BIM), a technology that applies computer generated 3D/4D models to simulate and communicate the life cycle of a facility (Azhar et al. 2008). Project participants -- designers, engineers and contractors -- use BIM to visualize the project in a simulated environment in order to identify potential problems in advance, even before the project begins (Eastman et al. 2008). Because of the apparent benefits gained from BIM, it has now become wide spread in the entire industry (Azhar et al. 2008). As suggested by McGraw-Hill’s *Smart Market Report on Interoperability*, 2008 was the tipping point for BIM in the sense that, after 2008 it has become an inevitable technology in the industry (Gudgel 2008).

#### *2.1.4.2 Studies on behavioral and attitudinal perspectives of individual cooperation*

Besides the focus on instrumental aspects of cooperation, a small but fast growing group of scholars have noticed the importance of looking into the social, behavioral and cultural aspects of cooperation (Cheung et al. 2003; Shek-Pui Wong and Cheung 2004). Barlow and Cohen (1996) highlighted the importance of mutual goals, interpersonal trust, and an appreciation of each other’s commitments in the formulations of most present partnering.

Green and McDermott (1996) found an embedded culture in construction settings where the attitudes and behavior of project team members are deeply ingrained, so it is difficult for project teams to rapidly change the organizational environment (e.g., moving to partnering). Besides, cumulative evidence highlights the importance of behavioral and attitudinal factors in forming a successful collaborative project team, including commitment, trust, and mutual respect (Li et al. 2000; Cheung et al. 2003). Efforts have been made to quantitatively link behavioral and attitudinal factors to the ultimate performance of team integration effort (Cheung et al. 2003; Shek-Pui Wong and Cheung 2004). For example, Cheung et al. (2003) conducted an extensive survey to examine the factors affecting the quality of partnering. The findings indicate that attitude oriented factors explain the most variance (0.818). However, although these attitudinal and behavioral factors are regarded as central to establishing a cooperative culture in project teams, the fashion in which they are formulated is less clear (Bresnen and Marshall 2000b). Limited efforts have been made to investigate the mechanism and process of how these behavioral and attitudinal factors shape or affect cooperation in construction project teams. As described by Kadefors (2004), pivotal behavioral and attitudinal factors of team cooperation or integration remains a “black box”.

It is worth noting, however, that some scholars have recently started looking into the formation mechanism of cooperation or integration of construction project teams, instead of simply providing statistical evidence (Chinowsky et al. 2009; Son and Rojas 2010; Unsal and Taylor 2010). Assuming construction project teams are temporary



organizations, Son and Rojas (2010) developed an Agent Based Model to investigate the evolution of cooperation within inter-organizational networks of construction project teams from the game theory and social network perspectives. Their findings revealed a set of rules regarding the evolution of cooperation among participants from different organizations. For example, they confirmed that the fewer individuals are familiar with others in the inter-organizational network, the longer time it takes for networks to reach stable states. Additionally, the tendency of cohesion increases as the effort to form relations with outside partners rises. Furthermore, the efficiency of inter-organizational networks is negatively correlated with the efforts needed to form relations with those from other organizations (Son and Rojas 2010). This work highlights the role of interpersonal cooperation in forming a robust inter-organizational project network.

Unsal and Taylor (2010) integrated an Agent Based model with game theory to examine contractors' subcontractor selection as a repeated game. Their investigation centered around the contractors' investments in learning by introducing an innovation-oriented organizational change across the project network. The findings indicate that a long term relation-based selection strategy might increase the adaptation rate to an innovation-oriented organizational change. This work, in another sense, proves that cooperation between a contractor and subcontractors builds on willingness to establish a long term relationship. Chinowsky et al. (2009) introduced an innovative modeling approach, Project Network Interdependency Alignment, to identify potentially excessive or insufficient communication and knowledge exchanges in a project network which can

make projects ineffective. They found that project effectiveness is highly dependent on the alignment of actual knowledge exchanges with knowledge exchange requirements across task-organization network dyads. Their work reproduces the process of how the interdependency of project participants, in terms of knowledge sharing, shapes the effectiveness of a project. The difference between these newly emerged studies and previous survey based studies is that they place more attention on the formation process of cooperation between individuals from different organizations, while previous efforts were more interested in revealing the ultimate quantitative relationships between driving factors (such as trust, commitment) and the level of cooperation.

#### *2.1.4.3 Four quadrants of cooperation studies in the construction area*

Following the above discussion about cooperation studies and enhancement practices, it was found that current studies and practices concerning better understanding and enhancement of cooperation in construction project teams can be framed into four quadrants as illustrated in Table 2.2. They are organizational level with a focus on instrumental aspects of cooperation, individual level with a focus on instrumental aspects of cooperation, organizational level with a focus on behavioral aspects of cooperation, and individual level with a focus on behavioral aspects cooperation.

In particular, this study has put special emphasis on the behavioral and attitudinal perspectives of cooperation at the individual level, with a consideration of the

organizational and procedural arrangement. This is because of the nature of construction project teams.

**Table 2.2** Quadrants of cooperation enhancement practices and studies

	<b>Instrumental perspective</b>	<b>Behavioral perspective</b>
<b>Organizational level</b>	Partnering Strategic alliance IPD BIM Inter-organizational collaboration	Relational management Network between organizations Inter-organizational trust Inter-organizational relation Inter-organizational dependence
<b>Individual level</b>	Organizational hierarchy Job responsibility Coordination	Social network between individuals Interpersonal trust Interpersonal commitment Interpersonal relationships Interpersonal cooperation

## **2.2. Construction project teams**

### **2.2.1. Definition of construction project team**

Despite numerous definitions in the literature (Verville and Halington 2003), a representative definition of team has been given by Kozlowski and Bell (2003):

*“A team is a collective who exists to perform organizationally relevant tasks, share one or more common goals, interact socially, exhibit task interdependencies, maintain and manage boundaries, and are embedded in an organizational context that sets boundaries, constrains the team, and influences exchanges with other units in the broader entity.”*

This definition captures certain key elements of construction project teams. Particularly, it reveals the fact that a team is a collective with many levels of interdependence and it operates in an environment that determines the quality of functioning. However,

construction project teams have certain unique features that are not reflected in this definition. On a construction project, a project team is comprised of colleagues from different functions (for example, estimation, scheduling, and accounting departments are brought together to perform project planning) and disciplines (architects, engineers, and contractors form a team to perform project activities) who interact regularly to execute project related tasks and activities, but there is no permanent set of boundaries for construction project teams. Plus, this approach means a construction project team is probably embedded in multiple organizational contexts (since its members may come from different organizations instead of just one). Moreover, construction project teams are project-based organizations, which means that completing project goals instead of organizational goals is a better description of the construction project team's essential function (Thiry and Deguire 2007). Therefore, based on Kozlowski and Bell's definition with a consideration of the uniqueness of construction project teams, this study offers the following definition for construction project teams:

*A construction project team is a temporary collective with members from different functions and disciplines. It performs construction project related tasks, shares mutually agreed project goals, interacts regularly, demonstrates task interdependencies, and is embedded in particular organizational contexts which determine the quality of its functioning.*

### **2.2.2. The characteristics of construction project teams**

Several unique features distinguish construction project teams from other kinds of groups. First, construction project teams are usually regarded as temporary organizations (Son and Rojas 2010). The construction industry is represented by a huge number of small sized and distributed players (Bureau of Census 2011). On the one hand, single construction organization hardly have the necessary ability to perform all the activities of a project (Son and Rojas 2010). Even within a construction organization, given the increasing complexity of construction project tasks, there is a need to coordinate between various functional departments within the organization (Ahuja et al. 1994). Thus construction projects, especially those that are large and complex, are ultimately built on a collaborative effort across the boundaries of a number of construction organizations or functionalities (Son and Rojas 2010). On the other hand, construction projects are also usually “one-of-a-kind” efforts, i.e., no project before or after will be exactly the same. As a result, when there is a project, different disciplines or functions are brought together to form a construction project team; but once the project is finished, the team will be dismissed immediately (Alshawhi and Faraj 2002). This nature of construction projects creates a need for *“temporary modes of operation and thereby tends to promote highly dispersed management practices that do not dovetail very well with other organizational processes”* (Bresnen et al. 2005). There is seldom a common organizational structure existing in construction project teams, and the hierarchy and power alignment varies depending on the individuals involved (Newcombe 1996).

Second, the increasing use of outsourcing has led researchers to introduce the term “virtual teams” to describe construction project teams (Nayak and Taylor 2009). Chinowsky and Rojas (2004) defined virtual teams in engineering, procurement, and construction activities as “a group of people with complementary competencies executing simultaneous, collaborative work processes through electronic media without regard to geographic location.” The increasing application of “virtual” in the construction industry comes from the advances in technology and market globalization in recent years (Nayak and Taylor 2009). On the basis of emerging information communication technologies, a growing number of construction companies are outsourcing portion of their work to vendors, such as those in IT systems (Barthorpe et al. 2004), and complex project design (Joseph 2005). A recent survey reveals that 44% of engineering companies in the United States are using outsourcing to release cost burden and improve efficiency (Bryant 2006). Due to the significant geographic distances that separate clients from vendors, much teamwork is executed in a fashion that crosses time, space, organizations and cultures (Maznevski and Chudoba 2000). Besides the potential benefits gained from virtual teams, the construction literature has already noted the challenges faced in virtual project teams, such as issues concerning communication, trust development and quality control (Nayak and Taylor 2009).

Third, construction project teams can also be considered as a “potential team” following the work of Katzenbach and Smith (1993). Katzenbach and Smith (1993) proposed the “team performance curve” theory to differentiate team into five types according to their

level of effectiveness and impacts on performance: “working group”, “pseudo team”, “potential team”, “real team” and “high-performance team”. The definition and major features of each team are given in Table 2.3. According to their definition, most construction project teams can be categorized as “potential teams”: construction project team members are actively engaged in project activities, but hesitate to fully coordinate and contribute their efforts because each member represents the interests and foci of his/her own organization or department. As a result, team conflicts, disagreements and misunderstandings are commonly seen in construction project teams. Katzenbach and Smith (1993) found that although the members were targeting the same goal, conflict and an unpleasant atmosphere were almost inevitable. The “potential” therefore refers to the chance to become a real or high-performance team through team development including effective training, cooperation experience, realigned business goals or even, simply, time (Katzenbach and Smith 1993).

**Table 2.3** Five types of teams; modified from (Katzenbach and Smith 1993)

<b>Types</b>	<b>Definition</b>	<b>Relationship between members</b>	<b>Team’s impacts on performance</b>
Working group	<p>A group with no clearly defined performance goal or need to become a team. The members might share information with each other primarily in order to help within individual job responsibility.</p> <p><b>Example:</b> A group of administrative staff whose tasks include answering phones and scheduling appointments. They are all working as part of the same group, but have no common and measurable goal to attain (Feinberg</p>	Team members are loosely grouped	There is no “common goal” and team’s impact on the performance is very low

**Table 2.3** Cont'd

Types	Definition	Relationship between members	Team's impacts on performance
	2009).		
Pseudo team	<p>A group which might have performance goals but doesn't focus on collective effort to achieve the desired results.</p> <p><b>Example:</b> A group of people who claim they are a team, but has no interest to develop a common goal (Feinberg 2009).</p>	Nominal working relations between team members have been developed	Performance goal are not addressed at all or are superficially defined
Potential team	<p>A group might have an agreed performance goal and members might try to work towards the goal; but the goal needs clarification.</p> <p><b>Example:</b> A project team with members from different disciplines working towards the completion of the project; however, conflicts always exist because they represent the interest of different organizations or departments (Katzenbach and Smith 1993).</p>	Team members are actively involved in team tasks, but have not fully contributed their efforts.	There is a common performance goal, but needs clarity about purposes, goals, and requires the development of a common work approach
Real team	<p>A small number of members who are committed equally to agreed mutual goals working closely together to prove their accountability as a member in the team. Normally, team members have complementary skills.</p> <p><b>Example:</b> A surgical team performing a heart transplant. This team consists of medical specialists ranging from nurses to various doctors. Team members' skills are highly matched and team goal is clear and determinant (Feinberg 2009).</p>	The members have complementary skills, and cooperate (rather than compete) with each other. Team structure is clear and effective.	Team members have a clear performance goal and team's impacts on performance is very high
High performance team	<p>A group that builds on a real team, with all members completely committed to each other with respect to personal success and growth.</p> <p><b>Example:</b> Manhattan Project's members built their personal growth on the success of the project (Bodwell 2006).</p>	The members are highly collaborative and committed to each other	A very high impact on performance



### **2.2.3. Cooperation research suitable for the features of construction project team: from “top-down” to “bottom-up”**

Given the features of construction project teams (i.e., temporary, virtual and potential), the position and scope of the proposed cooperation research must consider the uniqueness and critical needs of construction project teams. This study's positions and scope are based on the following arguments:

First, the contention that construction project teams are temporary teams highlights the need to examine the relational factors (e.g., interpersonal cooperation, trust and commitment) between team members instead of legitimation building. Lundin and Soderholm (1995) found that, in temporary organizations, the relationships between individuals, such as commitment building, are of central interest, compared to legitimation building. Individuals hold their own defined expectations and carry different levels of experience into the team. These experiences and expectations are possibly different or even conflicting (Lundin and Söderholm 1995). Moreover, every member in a temporary organization knows exactly that there is an specified end to the collective effort, and individuals could also come and go at different times in the team (Miles and Laboratories 1964), as a result the “rules of the game” may frequently change since new members may appear at any time (Lundin and Söderholm 1995). Therefore, common organizational structure or hierarchy does not count; rather, interpersonal relational factors, such as interpersonal commitment (Lundin and Söderholm 1995), trust (Kanawattanachai and Yoo 2002), and interpersonal cooperation (Bijlsma and Costa 2003) constitute the

basis for forming a temporary organization. This argument has been supported by the construction literature: Chinowsky et al. (2010) proposed a social network model to depict the relations between team members in a construction project. The findings indicate that a project network has no stabilized structure among different projects. As such, it was found that professional trust, effective interpersonal communication and knowledge sharing form the foundation of delivering a successful construction project (Chinowsky et al. 2010). All the evidence above implies that cooperation research suited to the construction context should pay special attention to the relational factors among project team members.

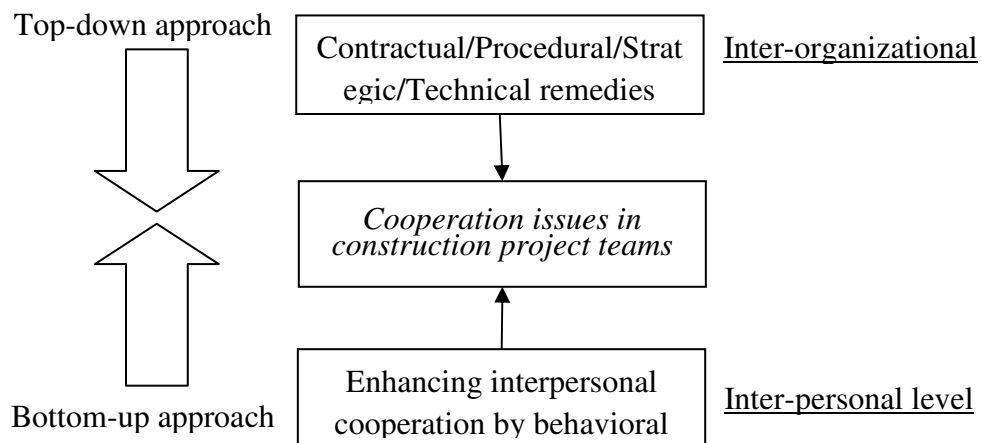
Second, the view of construction project teams as virtual teams highlights the importance of social aspects of cooperation between team members in terms of fostering the cooperative efforts of the team. Due to geographical distribution, face-to-face communication rarely occurs in many construction project teams. This results in weaker social relations between team members and makes the team become more “task-focused” rather than “socially focused” (Powell et al. 2004): cohesion and trust among team members becomes more difficult when people rarely meet face-to-face (McDonough III et al. 2001); Effective communication and coordination among team members are considered as serious challenges (Nayak and Taylor 2009); and interpersonal relationships between team members are very hard to build (Robey et al. 2000). Therefore, Powell et al. (2004) highlighted the significance of social-emotional problems involved in bringing team members closer and forming interpersonal cooperation in virtual teams. Although

social-bonding can be accomplished partially via electronic communication tools (Joseph 2005), it was argued that the focus of virtual project teams remains on relationship building rather than on actual business (Robey et al. 2000). In short, studying cooperation issues in construction project teams must emphasize the social-emotional process between team members.

Last, the potential team nature of construction project teams indicates that the future trend in team performance improvement should focus on aligning the efforts of individuals and building long term cooperative relationships between team members. A variety of construction literature has already highlighted the need to move from traditional project teams to high-performance project teams in the construction industry (Jenner 1997; Boetti and Leandro 2008; Novelo and Gabriel 2010). This will require additional research efforts to investigate the characteristics of high performance project teams (Novelo and Gabriel 2010). According to Katzenbach and Smith's performance curve theory (Table 2.3), the difference between a potential team and a high-performance team is lack of interpersonal alignment and long term commitment and trust between team members (Katzenbach et al. 1993). Therefore, the fundamental step for building future high performance construction project teams is figuring out how to coordinate the efforts of project team members, as well as exploring why people form long term interpersonal relationships in a construction project team. To achieve this target, the first step is to better understand interpersonal cooperation mechanism in construction project teams is necessary; i.e., why and how people cooperate in a construction project team.

The natural features of construction project teams offer a clear clue to what the proper research positioning for cooperation research should be in the construction context. Most existing efforts have put too much emphasis on organizational collaboration and strategic alignment as discussed in previous sections. Such a method aims to provide a remedy of cooperation issues in the construction industry through “top-down” contractual, institutional and strategic improvements. Although this has worked to some extent, the “top-down” approach has proven insufficient to capture the real needs of enhancing cooperation in construction project teams (Moore and Dainty 2001).

Based on the analysis of the natural features of construction project teams, this study proposed that a “bottom-up” approach, i.e., investigating the behavioral and attitudinal aspects of cooperation at the individual level, is a good fit for cooperation research in the construction context (Figure 2.2). It is expected that, by enhancing interpersonal cooperation, especially by behavioral changes of team members, new insight into cooperation issues in construction project teams will be advanced.



**Figure 2.2** Two approaches to enhancing cooperation in construction project teams

#### **2.2.4. Performance of construction project teams**

Team performance, in general, is a multifold concept. The literature has suggested that team performance could be defined at different levels and for different perspectives (Klammer 2002). First, team performance is defined by the literature at different levels. In 2008, Mathieu et al. conducted an extensive review on the team performance literature from 1997 to 2007. They found that the literature uses team performance on three levels: organizational-level performance, which considers team and organizational outcomes as identical; team behavior and outcome performance, which defines team performance as the process toward and results of the expected performance goal; and role-based performance, which considers team performance as team members' individual performance (Mathieu et al. 2008). Second, the literature also tends to define team performance from different perspectives. Based on the work of Cohen and Bailey (1997), Klammer (2002) summarized the use of team performance in the literature, and highlighted three dimensions of team performance that are commonly used in research pertaining to teams: behavioral dimension, attitudinal dimension and outcome measures (i.e., the quantity and quality of outputs). As a result, Salas et al. (2007) found the use of team performance is quite mixed in current literature, with more than 130 different frameworks for team performance. Following the above notion, Table 2.4 demonstrates the dimensions of team performance on the basis of the literature (Salas et al. 2007).

**Table 2.4** The dimensions of team performance

<b>Organizational level</b>	<i>Measurements</i>	<i>Measurements</i>	<i>Measurements</i>
<b>Team level</b>	<i>Measurements</i>	<i>Measurements</i>	<i>Measurements</i>
<b>Individual level</b>	<i>Measurements</i>	<i>Measurements</i>	<i>Measurements</i>
	<b>Outcome/process measures</b>	<b>Behavioral measures</b>	<b>Attitudinal measures</b>

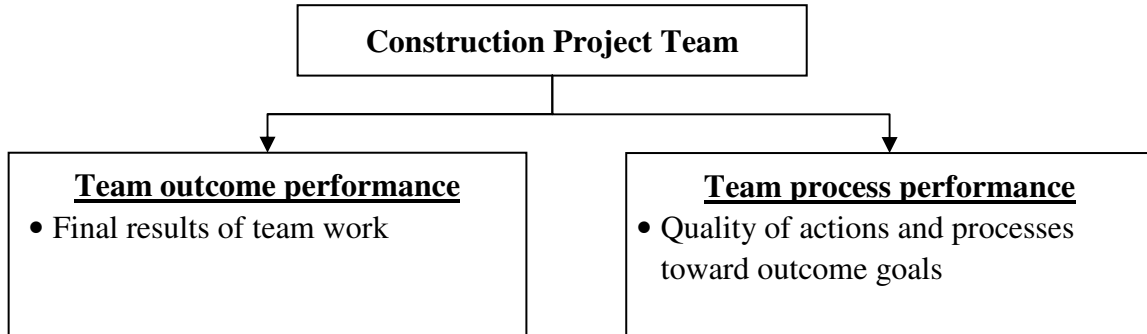
Because of the mixed meaning of team performance, Brannick et al. (1997) suggested that team performance should be defined to fulfill a variety of perspectives including “purpose of measurement,” “measurement attributes,” and “measurement process.” The definition and measure of team performance, therefore depend on the needs. For example, if the purpose is to evaluate the results of teamwork training, the performance of individuals within a team is the best measure. But if the purpose is to reward a team, it is better to evaluate the performance of the entire team. The same way, emphasizing behavioral and attitudinal performance indicators, or outcome performance indicators should be considered within the context (Brannick and Prince 1997). In construction context, Rojas-Villafane (2010) argued that team performance should be defined as how well the construction project team has worked to achieve its predefined goals, and it must highlight aspects under the control of the team. According to this claim, Rojas-Villafane (2010) grouped construction project team performance into process performance (or team work performance), and outcome performance (or task performance). Team outcome

performance refers to how well the team did its job; and process performance measures how the team performance is developed and improved over time (Rojas-Villafane 2010).

Rojas-Villafane's argument is confirmed by the construction literature. The use of team performance in construction publications can be grouped into two trends. One measures team performance as the assessment of team outcomes, such as time, cost, quality, productivity, risk and others (Barrick et al. 1998; Tesluk and Mathieu 1999; Langfred 2000; Kim and Burton 2002; Horii et al. 2005a; Kang et al. 2007; Leicht et al. 2010), and the other trend measures team performance based on the quality of the team's actions and processes toward the accomplishment of outcome goals, such as efficiency and effectiveness of communication among team members, wasted time, coordination time, rework time, accumulative unfinished work, effective working time, and manager rated work efficiency (Ancona and Caldwell 1992; Tommelein et al. 1999; Wong and Burton 2000; Chinowsky et al. 2010). Following the above notions, this research defines construction project team performance as the final result of team work, i.e., team outcome performance, and the quality of the actions and process toward the outcome goals in particular construction projects, i.e., team process performance (Figure 2.3).

Previous literature review has served as the theoretical foundation to build a conceptual framework for interpersonal cooperation in construction project teams. In order to convert the conceptual framework to an executable simulation model, simulation methods were

reviewed. It was found Agent Based Modeling to be a perfect fit for this research. In the following section, ABM is introduced.



**Figure 2.3** The framework of construction project team performance

## **2.3. Agent Based Modeling: a bottom-up approach**

### **2.3.1. Concepts**

As a computational modeling approach, Agent Based Modeling (ABM) is a suitable tool for use in social research to study human and organizational issues in a diversity of areas (North and Macal 2007). It is a computational method that builds a common environment for heterogeneous and autonomous agents to share, and allows the agents to simultaneously interact with each other for self-interest (Ligmann-Zielinska and Jankowski 2007). Unlike top-down modeling approaches (e.g., System Dynamics, Discrete Event Simulation etc.), in ABM the collective behavior of the simulated system is not predefined, but emerges from individual agents who act based on what they perceive to be their own interests. Thus, ABM is capable of reproducing the emergent properties of the studied systems (Macal and North 2007).

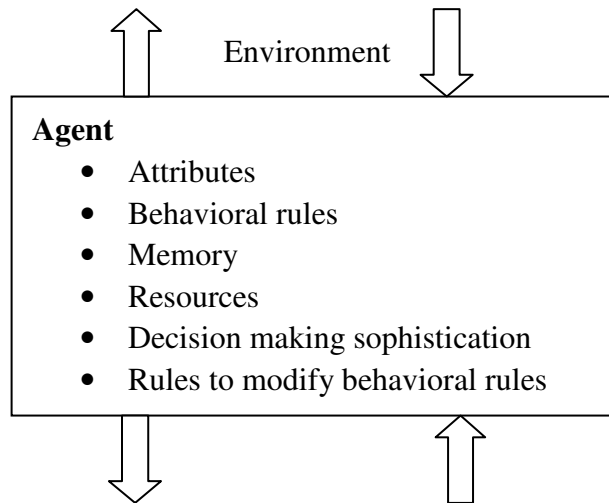


#### *2.3.1.1. Agent*

The fundamental concept of ABM is “agent,” i.e., the basic unit that makes independent decisions in the model (Macal and North 2007). An agent is an artificial entity (a computational unit) that is able to perceive and act upon a common environment and make decisions independently for itself to satisfy its own objectives or interests (Macal and North 2007). Numerous arguments remain over the term “agent” because this idea has been applied in many different domains (Schieritz and Milling 2003). However, certain common characteristics of agent have been identified: Macal and North’s (2005) representative description of agent is:

- (1) Identifiable and discrete;
- (2) Self-contained with a clear boundary;
- (3) Situated in an environment where it interacts with other agents;
- (4) Goal-directed: has own set of goals that it actively acts to fulfill;
- (5) Autonomous: has a pool of attributes and rules determining its decision-making processes and corresponding behaviors;
- (6) Learning ability: able to adapt behaviors according to experience.

Additionally, Macal and North claimed that agent behaviors may vary in their complexity, availability of information, the internal models of agent’s toward the external world, and the extent to which an agent’s past memory can be retained in decisions (Macal and North 2005). Based on proposed features, they provided an agent framework as following figure:



**Figure 2.4** The framework of an agent; modified from (Macal and North 2005)

In organizational simulation, an agent may be seen as a person and/or a group of persons who share a congruent target and the same function (e.g. a department). Also, an agent can be seen as an organization in the macro environment. The definition of an agent in a practical model depends on the granularity of the model. In this research, an agent is regarded as an individual team member.

#### *2.3.1.2. A bottom-up approach*

ABM is a bottom-up approach (Bonabeau 2002). First, the fundamental elements of a system, i.e., agents, are defined in great detail. Then agents are linked together to build a series of subsystems, which in turn are connected again multiple times until a complete system appears (Epstein and Axtell 1996). For example, the Santa Fe Institute has begun the development of an artificial stock market since the 1990's. These "bottom-up" models always start from specified details of agent behaviors. On the basis of sophisticated

computational tools, these models can be used to describe macro characteristics of the real world stock market by “growing” from a group of interacting individuals (LeBaron 2002). In contrast, in top-down simulation, “aggregated quantities,” instead of the behaviors of individual agents, play the sole role of determining the system’s outcome (Ligmann-Zielinska and Jankowski 2007). The bottom-up approach of ABM makes it a perfect candidate for tackling the emergent properties of complex systems, which refers to the phenomenon that “*the whole is more than the sum of its parts because of the interactions between the parts*” (Bonabeau 2002). Because ABM “*models and simulates the behavior of the system’s constituent units and their interactions, capturing emergence from the bottom up*” (Bonabeau 2002), it has been regarded as a canonical approach to model emergent behaviors of construction systems (Prietula et al. 1998). Plus, because of the bottom-up feature, ABM has also greatly promoted the development of *Generative Social Science* which explores complex social processes as an emergent phenomenon growing from dynamic interactions between fundamental entities with simple rules and parameters (Epstein 1999).

### **2.3.2. Applications of ABM**

Fields in which ABM can be utilized range from biology to engineering (LeBaron 2002; Cederman 2003; Christiansen and Altaweel 2004; Gratch and Marsella 2004; Folcik and Orosz 2006). Macal and North (2007) summarized the main applications of ABM as in the following table:

**Table 2.5** The applications of ABM (Macal and North 2007)

<p>Business and Organizations</p> <ul style="list-style-type: none"> <li>• Manufacturing Operations</li> <li>• Supply chains</li> <li>• Consumer markets</li> <li>• Insurance industry</li> </ul> <p>Economics</p> <ul style="list-style-type: none"> <li>• Artificial financial markets</li> <li>• Trade networks</li> </ul> <p>Infrastructure</p> <ul style="list-style-type: none"> <li>• Electric power markets</li> <li>• Transportation</li> <li>• Hydrogen infrastructure</li> </ul> <p>Crowds</p> <ul style="list-style-type: none"> <li>• Pedestrian movement</li> <li>• Evacuation modeling</li> </ul>	<p>Society and Culture</p> <ul style="list-style-type: none"> <li>• Ancient civilizations</li> <li>• Civil disobedience</li> <li>• Social determinates of terrorism</li> <li>• Organizational networks</li> </ul> <p>Military</p> <ul style="list-style-type: none"> <li>• Command &amp; control</li> <li>• Force-on-force</li> </ul> <p>Biology</p> <ul style="list-style-type: none"> <li>• Population dynamics</li> <li>• Ecological networks</li> <li>• Animal group behavior</li> <li>• Cell behavior and sub cellular processes</li> </ul>
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ABM has been utilized by a small but growing community of scholars to tackle a range of difficult problems in the construction area, including engineering design (Soibelman and Pena-Mora 2000), project organizations and network (Jin and Levitt 1996; Horii et al. 2005a; Taylor and Levitt 2007; Du and El-Gafy 2011), construction operations (Mohamed and AbouRizk 2005; Watkins et al. 2009; Kim 2010), project management (Christodoulou 2010), supply chain (Xue et al. 2005), construction policy (Ducrot et al. 2004), construction safety (Walsh and Sawhney 2004), and evacuation in different building environments (Zheng et al. 2009). Although the topics are diverse, the foci of interest can be grouped into three categories:

- **Project organizations:** Increasingly, scholars are proposing the use of ABM to study the complex behaviors of project organizations and networks, e.g.,

organizational performance, work related behaviors, project team cooperation, and cross-cultural issues (Jin and Levitt 1996; Horii et al. 2005a; Taylor and Levitt 2007; Du and El-Gafy 2011). Representative work in this area is Virtual Design Team, or VDT (Jin and Levitt 1996). As a multi-agent based simulation platform, VDT aims to investigate issues in project based organizations (Jin and Levitt 1996). By merging the organizational structure with a project's task precedence diagram, VDT analyzes how interdependencies between concurrent activities introduce additional coordination needs, and how organizational structure and communication tools change the "coordination capacity" of project teams (Jin and Levitt 1996). As a well-documented and well-validated organizational simulation tool, it has been widely applied to studying project based organizations to estimate project durations, costs, and quality. Many models have been extended from VDT to investigate organizational learning, project network dynamics, integrated technology impacts, and organizational alignment (Ortiz de Orue et al. 2009; Unsal and Taylor 2009; Wong et al. 2009).

- **Construction site:** These applications focus on the issues on a construction site, such as onsite operations, equipment logistics, safety, and evacuation (Walsh and Sawhney 2004; Mohamed and AbouRizk 2005; Watkins et al. 2009; Kim 2010). Watkins et al. 's work (2009) is representative. Using ABM, they reproduced a simple masonry work site to explore the potential effects of individual and crew interactions. Especially, they were interested in investigating the impacts of

construction site congestion on productivity. Their work revealed that there is a nonlinear relationship between the number of laborers and overall productivity. They proposed that ABM can be “used to efficiently utilize construction space, and develop plans and schedules that account for congestion arising from crew interactions in space” (Watkins et al. 2009).

- **Project management:** These applications utilize ABM to enhance traditional project management, such as project scheduling, resource optimization, and supply chain management (Xue et al. 2005; Christodoulou 2010). For example, Christodoulou (2010) created an ant colony optimization (ACO) model using ABM to address the project schedule optimization problem. He found that it is very difficult to schedule projects with strict resource constraints using traditional approaches, such as Critical Path Method (CPM); instead, ABM performed better on such problems. The findings indicate a high accuracy (97%) of using ABM as an enhanced scheduling approach in resource-constrained projects (Christodoulou 2010).

### **2.3.3. The rationale for using ABM in this research**

There are several reasons driving the use of ABM in the proposed research. First, ABM is a natural fit for the proposed bottom-up approach of investigating interpersonal cooperation in construction project teams. As discussed in the previous section (section 2.2.3), this research proposes studying the micro-level behaviors of individuals to gain deeper insight into the cooperation issues in the construction industry, because of the

natural features of construction project teams. This requires a comparable research approach which can reproduce the transition from individuals to collective behaviors. Epstein's description of using ABM to accomplish generative research is a perfect example: ABM generates a population of autonomous and heterogeneous agents (e.g., project team members), defines decentralized behaviors, and allows them to interact with each other by simple rules, and therefore "grows" the macro results from the bottom up (Epstein 1999). A variety of construction studies have used ABM to support a bottom-up investigation (Walsh and Sawhney 2004; Watkins et al. 2009). It is expected that the relationship between individual behavior and overall cooperation in construction project teams is complicated; therefore ABM is a canonical approach to use in this research.

Second, ABM is able to capture the complexity embedded in cooperation issues in construction project teams. Construction project, by its nature, is a complex system (Bertelsen 2003a). Even in average projects, there are numerous topologies of the interactions among project team members, heterogeneous participants' behaviors, and inevitable uncertainties (Pich et al. 2002a). Schalcher (2009) further concluded that the highly interacting construction project teams and the entire construction process as well as various interrelated activities, contribute to the complexity of construction projects. These interactions, mostly between project team members, are nonlinear and dynamic; thus they are difficult to study using pure mathematical and statistical analyses. In this sense, ABM is a good candidate for mapping the complexity of the cooperative process in construction

project teams since it begins with agents' preferences and behaviors, as well as interactions among them (Bonabeau 2002).

Third, ABM provides a natural description of the studied system, i.e., cooperative process in this research, which enables a better understanding of research problems, and enhances the communication between the modeler and the participants (Bonabeau 2002). The proposed research, building on real construction project data, involves an intensive communication between the researcher and the domain experts (i.e., practitioners under study). Top-down modeling, such as System Dynamics (SD), requires domain experts to have a global understanding of the studied objects. In the construction domain, however, practitioners typically have no insight into the overall processes, only their own responsibilities and rules. This makes the communication of modeling results a problem in top-down modeling. Instead, ABM works on micro-level processes and describes the problem by reproducing each "behavioral" entity, i.e., the actions of a real team member. This strategy provides a realistic picture for domain experts and thus enhances the understanding of the model.

Given the above reasons, ABM is a good fit for studying the interpersonal cooperation issues in construction project teams.

## **2.4. Summary**

This chapter has reviewed an extensive body of literature pertaining to cooperation theories, previous cooperation studies in the construction literature, theory about



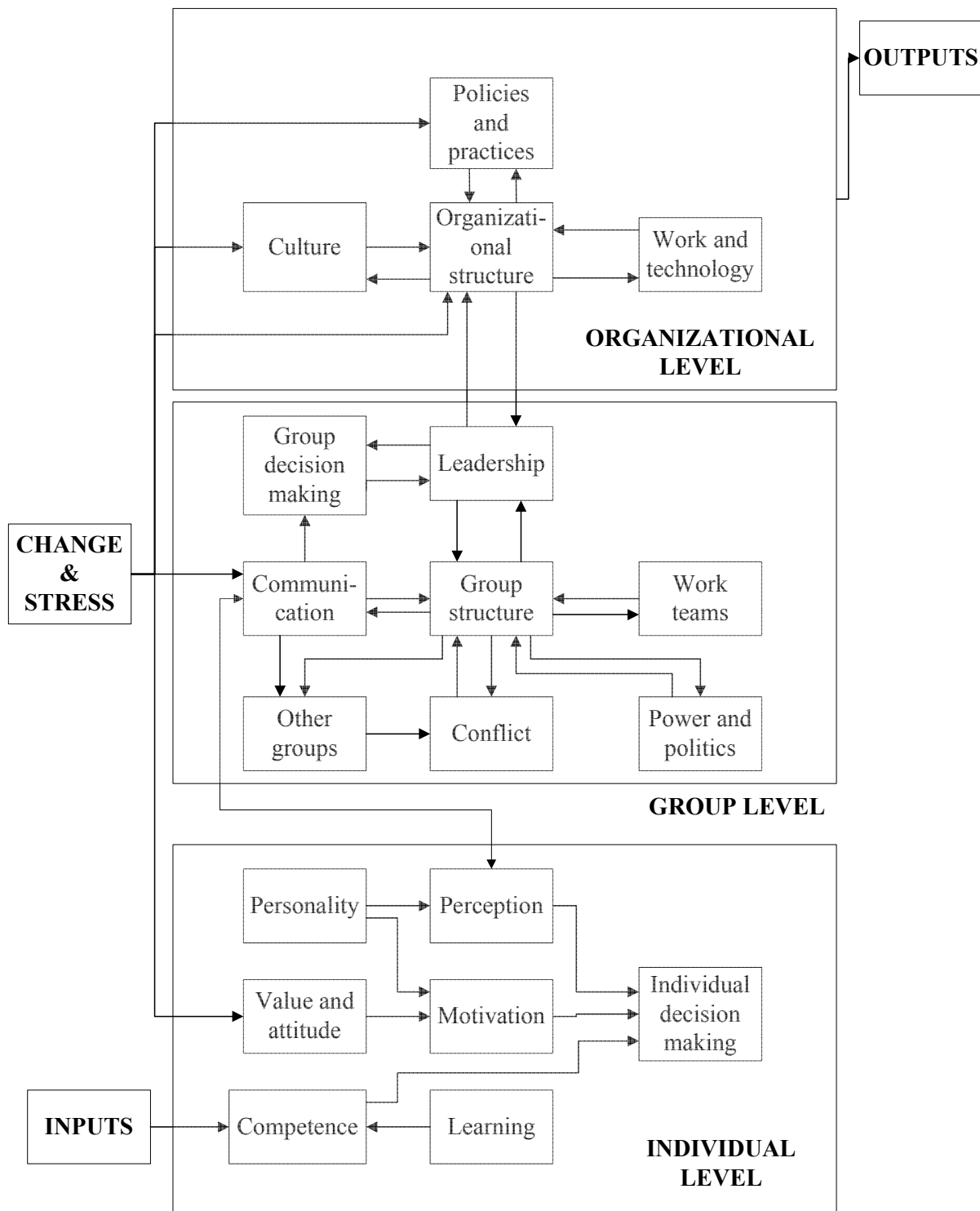
construction project teams, and simulation technologies. The literature review identified gaps of current studies and practices of cooperation in construction project teams, introduced basic concepts and characteristics of cooperation and project team, and validated the rationale of using ABM as the simulation method. This chapter builds a solid point of departure for this research. In the next chapter, literature review is extended to a deeper level to develop a conceptual framework for interpersonal cooperation in construction project teams.

### **CHAPTER 3: A CONCEPTUAL FRAMEWORK OF INTERPERSONAL COOPERATION IN CONSTRUCTION PROJECT TEAMS**

This chapter extends the literature review to build a conceptual framework specified for studying interpersonal cooperation and its implications in construction project teams. In particular, generic driving factors of interpersonal cooperation are discussed with relevant theories and studies; factors that are critical in the construction context are highlighted; a list of performance metrics is identified as the index for quantifying the effects of interpersonal cooperation on the performance of construction project teams. Finally, a conceptual framework is developed based on an IPO (Input-Process-Output) view of organizations.

#### **3.1. Cooperation: a system perspective**

Following recent findings of organizational science (Robbins 2005), individuals, teams and groups act interdependently in organizations to achieve an ultimate goal. On the one hand, psychosocial conditions of individuals, as the fundamentals of organizational processes, significantly affect the technical quality of any formal or informal group activities. On the other hand, the team runs as a group of distinct individuals and exerts noticeable impacts on behaviors (Robbins 2005). People-organization relationships play an irreplaceable role in forming organizational behavior and defining the outcomes. Building on Robbins and Langton's (1998) model of organizational behavior (Figure 3.1), work performance is human output dependent on individual behaviors, group behaviors and the organizational system, and affected by environmental change and stress.



**Figure 3.1** Model of organizational behavior; modified from (Robbins and Langton 1998)

Robbins and Langton's work (1998) constitutes the point of departure of this research to explore the constituents of cooperation. It suggests a system approach to be adopted in the

investigation of interpersonal cooperation, considering interactions of a variety of process levels including individual level, group level and organizational level. As addressed by Bresnen and Marshall (2000b), any contribution leading to a better understanding of the cooperation concept that integrates the multiple theoretical perspectives in construction project teams would be a significant contribution to construction knowledge.

In addition, it is worth noting that these processes have different weights in the construction context. For example, in design bid build projects, conflict management as a part of team process is typically important because inter-organizational cooperation between project parties (e.g., owner, general contractor, and sub-contractors) determines the quality of teamwork and ultimate project performance (Vaaland 2004). Therefore, constructs of interpersonal cooperation should be differentiated according to their importance to construction projects and project teamwork.

An extensive literature review was therefore conducted, and the result supports the assumption. An overall analysis on the cooperation literature highlighted the fact that cooperation literature themes can be naturally grouped into four categories: individual factors, relational factors, organizational factors, and task-related factors. These four categories of factors define interpersonal cooperation in construction settings. The remainder of this chapter summarizes the literature findings in detail.

### 3.2. Antecedents of interpersonal cooperation in construction project teams

The literature review highlights the important roles of four categories of factors in the formation of interpersonal cooperation in construction project teams, including individual factors, relational factors, organizational factors, and task-related factors. Therefore, this research proposes that the antecedent variables of interpersonal cooperation in construction organizations can be grouped into four distinct categories: (1) task characteristics; (2) individual characteristics; (3) relational behaviors; and (4) organizational context. Table 3.1 lists the categorized factors that shape interpersonal cooperation, and identifies generic factors and those that are specific for construction project teams. In the following sections, more detailed findings from the literature review are discussed.

**Table 3.1** Antecedents and determinant factors of interpersonal cooperation

	Factors	Explanation	Reference and Researches
Task characteristics	Task dependence (Construction specific)	The extent to which team members are dependent on each other to perform individual tasks. <b>Representation:</b> work flow; information need; a probability that a task should be halted when others are undergoing.	(Deutsch 1949; Van de Ven et al. 1976; Hechter 1988; Winch 1989; George 1992; Pinto et al. 1993a; Baccarini 1996; Jin and Levitt 1996; Loch and Terwiesch 1998; Kazanjian et al. 2000; Thompson 2003; Levitt 2007; Chinowsky et al. 2009; Taylor et al. 2009; Chinowsky et al. 2010; Unsal and Taylor 2010)
	Task uncertainty (Construction specific)	The variability and difficulty to performance a particular task. <b>Representation:</b> level of complexity and repetitiveness	(Van de Ven et al. 1976; John and Martin 1984; Winch 1989; Moenaert and Souder 1990; Pich et al. 2002b; Whitley 2006)
	Task visibility (Construction specific)	The extent to which the environment allows the evaluation and monitoring of	(Souder 1981; Allen 1984; Davis 1985; Moorman et al. 1993; Itoh 1994; Wagner III

**Table 3.1** Cont'd

	Factors	Explanation	Reference and Researches
		individual performance in a group. <b>Representation:</b> the relevance of a task	1995; Ballard and Howell 1998; Soltani et al. 2002; Bowden et al. 2006; Fan et al. 2007; Xue et al. 2007)
Individual characteristics	Personality (Generic)	Personality traits that are important determinants of personal cooperativeness. <b>Representation:</b> especially agreeableness	(Taylor 1911; Fayol et al. 1929; Galbraith 1973; Allen 1984; Tellegen 1991; Kaman and McCambridge 1992; Kuprenas and Nasr 2000; Jesus and Vorster 2002; Varvel et al. 2004; Cheung et al. 2006; Pinto et al. 2009; Liu and Zhai 2010; Nakata and Im 2010; Nguyen et al. 2010; Yiu and Lee 2010) (Johnson and Singh 1998; Miller et al. 2000; Lawless 2001; Dikmen and Birgönül 2003; Fleetham and Griesmer 2006; Giritli and Civan 2008; Singh and Eng 2009)
	Roles (Construction specific)	Position of an actor engaged in group activities. <b>Representation:</b> individual hierarchical level and position in the work flow	(Pennings 1975; Chatman and Barsade 1995; Levitt 2007)
	Demographic characteristics (Generic)	Demographic factors that are important determinants of personal cooperativeness. <b>Representation:</b> e.g., age, experience, organizational tenure	(Gouldner 1954; March and Simon 1958; McCann et al. 1981; Ruekert and Walker Jr 1987b; Lu and Argyle 1991; Wagner III 1995; McCabe et al. 2005; Dabke et al. 2008; Davis and Songer 2009; Pinto et al. 2009; Shan 2010; Singh and Jampel 2010)
	Factors identified by CSF studies (Construction specific)	Other individual factors that are critical to work performance <b>Representation:</b> e.g., competence, supportiveness, organizing skills	(Bentley 1981; Graham 1989; Jaselskis and Ashley 1991; Belassi and Tukul 1996; Chua et al. 1999)
Relation	Communication (Construction	Certain tasks need extra information from other actors before processing. As such, team	(Laughlin 1978; Tjosvold 1988; Sally 1995; Jin and Levitt 1996; Clemmer et al.

**Table 3.1** Cont'd

Factors	Explanation	Reference and Researches
specific)	members need to exchange information and ideas for processing tasks.	1998; Malcurat et al. 2000; Shohet and Frydman 2003b; Hoegl et al. 2004; Wong et al. 2005; Chen and Tien 2007; Chinowsky et al. 2009; Balliet 2010; Migliaccio and Martinez 2010)
Coordination (Construction specific)	Finishing a particular task relies on different divisions of labor; therefore, the manager who is responsible for a task needs to coordinate between his/her subordinates; also, requesting or giving approval on particular tasks belongs to coordinating effort.	(Laughlin 1978; Trevino et al. 1987; Tjosvold 1988; Clemmer et al. 1998; De Saram and Ahmed 2001b; Hoegl et al. 2004; Consoli et al. 2007; Levitt 2007; Shen and Chang 2010)
Trust-related (Generic)	Trust-related behaviors are demonstrated as the attitude and preferences towards others' work. Literature indicates individual assessment on task quality is rather subjective. It reflects trust level between people. An actor compares the quality of delivered/submitted work with own quality threshold, and if quality is not satisfied, work will be reworked, returned, reassigned or reported.	(Bonoma 1976; Laughlin 1978; Tjosvold 1988; Bennett and Jayes 1995; McAllister 1995; Munns 1995; Clemmer et al. 1998; Korczynski 2000; Zineldin and Jonsson 2000; Wood et al. 2002; Bijlsma and Costa 2003; Hoegl et al. 2004; Kadefors 2004; Shek-Pui Wong and Cheung 2004; Diallo and Thuillier 2005; Wong et al. 2005; Bromiley and Harris 2006; Khalfan et al. 2007; Pinto et al. 2009; Girmscheid and Brockmann 2010)
Reciprocal (Generic)	Reciprocal activities come from the need to balance member contributions, i.e., all members of the project team should be equally involved to achieve shared goals and the members complement one another as best. Relevant behaviors include dealing with overloading, giving assistance to other team members, etc.	(Deutsch 1949; Thompson 1967; Laughlin 1978; Tjosvold 1988; Pinto et al. 1993a; Jin and Levitt 1996; Clemmer et al. 1998; Ahmad 1999; Thompson 2003; Hoegl et al. 2004; Fong and Lung 2007; Levitt 2007; Taylor et al. 2009; Unsal and Taylor 2010)
Discussion/me	Cooperation also builds on	(Antony 1976; Laughlin 1978;

**Table 3.1** Cont'd

	Factors	Explanation	Reference and Researches
	eting (Construction specific)	discussing problems and conflicts constructively, sharing a common purpose in discussion, and encouraging diverse viewpoints.	Raboud 1988; Tjosvold 1988; Schwartzman 1989; Boden 1995; Jin and Levitt 1996; Clemmer et al. 1998; De Saram and Ahmed 2001b; McCowan et al. 2003; Adams 2004; Hoegl et al. 2004; Tepper 2004; Levitt 2007; Ioannidou and Fruchter 2009)
<b>Organizational context</b>	Organizational structure (Generic)	The contractual/formal alignment of power, responsibility, and arbitrary job delegation pattern <b>Representation:</b> hierarchy, proximity, accessibility	(Ouchi 1980; Souder 1981; Keller and Holland 1983; Allen 1984; Davis 1985; Peters 1986; Hechter 1988; George 1992; Pinto et al. 1993a; Itoh 1994; Wagner III 1995; Anvuur 2008)
	Organizational rules and procedures (Generic)	How activities or tasks on the project team are mandated or controlled <b>Representation:</b> work procedures	(Pinto et al. 1993a) (Taylor 1911) (Fayol et al. 1929) (Gouldner 1954; March and Simon 1958; McCann et al. 1981; Galbraith and Nathanson 1982) (Ruekert and Walker Jr 1987b) (John and Martin 1984; Moenaert and Souder 1990; Moorman et al. 1993; Pinto et al. 1993a; Pinto et al. 2009; Nakata and Im 2010).
	Organization cultural norms (Generic)	Shared values that facilitate individuals to understand organizational functions and in return serves as common behavior norms in the organization <b>Representation:</b> individualism, collectivism	(Deshpande and Webster Jr 1989; Chatman and Barsade 1995; Wagner III 1995; Chen et al. 1998; Yilmaz and Hunt 2001; Nguyen et al. 2010)

### 3.2.1. Task characteristics

Task-related factors have been considered the most important component of cooperation (Yilmaz and Hunt 2001). The interest in task characteristics among cooperation scholars dates back to Deutsch (1949), who claimed that social interaction between people mainly



stems from the perceived dependence of individual goals towards tasks. As such, individuals tend to cooperate if they view the goals of tasks to be positively dependent and task characteristics require such cooperation to achieve dependent goals (Deutsch 1949; Deutsch 1973; Deutsch 1980). Extended by Deutsch and Krauss (1960) and Thompson (1967), Deutsch's theory has resulted in the growing interest to extend the pool of task characteristics as determinants of cooperation, such as task dependence, task complexity and task visibility (Van de Ven et al. 1976; Itoh 1994). In the following section, these task-related variables will be discussed in detail.

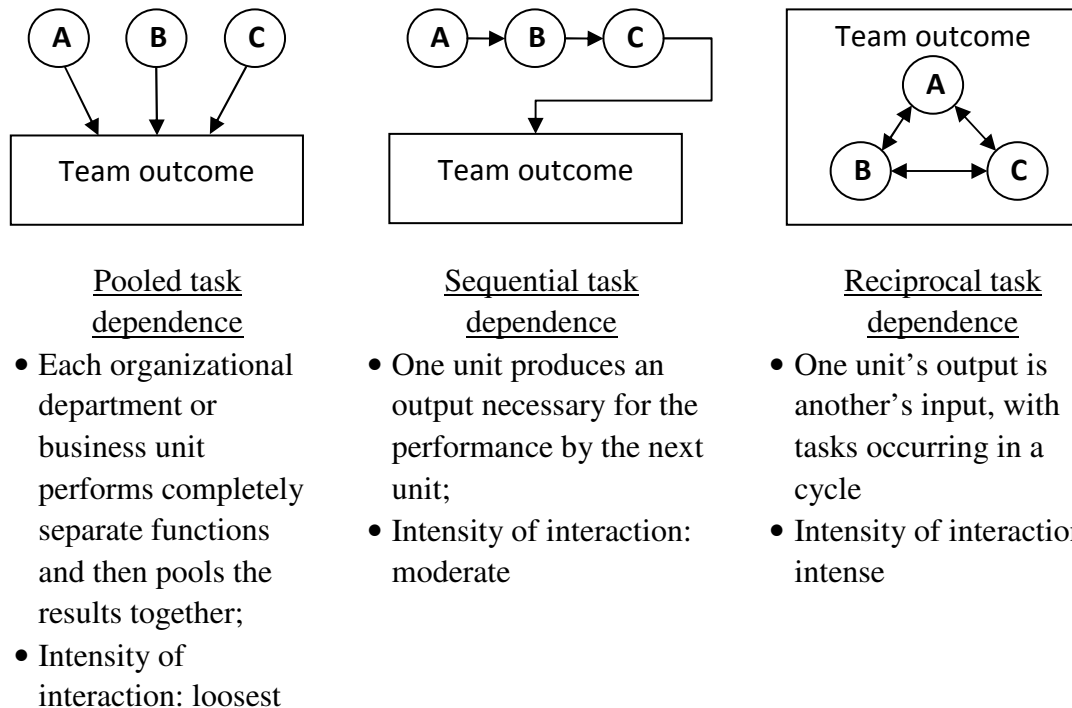
*3.2.1.1. Task dependence: The extent to which project team members are dependent on each other to perform individual tasks*

Task dependence refers to the extent to which team members are dependent on each other to perform individual tasks (Van de Ven et al. 1976). Among all the task-related factors, task dependence is considered to be most correlated to the level of cooperation in construction settings (Pinto et al. 1993; Thompson 2003). Because of the interdisciplinary of construction projects and iterative nature of construction activities, information of a construction project has to be synchronized and activities have to be coordinated well (Jin and Levitt 1996; Maheswari et al. 2006). Otherwise, it might produce mistakes necessitating rework and creating crises (Loch and Terwiesch 1998; Kazanjian et al. 2000; Thompson 2003). Therefore, in typical construction projects, task dependence of

operational and managerial activities is extremely important (Winch 1989; Baccarini 1996; Chinowsky et al. 2008).

The construction literature has recognized the importance of task dependence to be a moderator for cooperation enhancement intra- and inter- construction project teams (Jin and Levitt 1996; Levitt 2007; Chinowsky et al. 2009; Taylor et al. 2009; Chinowsky et al. 2010; Unsal and Taylor 2010). For instance, Unsal and Taylor (2010) found that task dependence can improve innovation adoption in a project network, and encourage the long term relationship between general contractor and subcontractors. Jin and Levitt (1996) suggested that managers' coordination efforts are highly dependent on the types and extent of task dependence. Thompson (1967) grouped task dependence into three types -- pooled, sequential and reciprocal -- with reciprocal dependence at their highest intensity of interaction (Figure 3.2). Regarding construction as a complex system (Bertelsen 2003b), reciprocal task dependence is probably the most common dependence in construction project teams (Thompson 2003). Because reciprocal task dependence means the highest level of interaction intensity (Thompson 1967), intense coordination work is required to adjust the efforts of different actors (Levitt 2007). In his seminal work, Thompson (1967) theorized that the correct way to get people working together effectively is to structure respective work tasks by intensity of dependence, and then manage each of those dependencies with different coordination methods. For example, a pooled dependency requires standardization in rules and operating procedures, while the coordination methods for the other two dependencies are slightly more flexible.

Especially for reciprocal dependence, “mutual adjustments” between each other and constant “information sharing” are needed.



**Figure 3.2** Three types of task dependence; self-made based on (Thompson 1967)

As to the measure of task dependence, Pennings (1975) pointed out that the measure of task dependence should cover four basic examples of interconnectedness between people: task (the flow of work between actors), role (the position of actors engaged in concerted action), social (mutual needs or goals of actors) and knowledge (the differentiated expertise of actors). Thompson (1967) defined dependence in terms of work flow and suggested that it be measured by focusing upon the flow of work, materials and objects between unit personnel. Building upon Thompson, it was induced that the hierarchy of increasing levels of task dependence between unit personnel can be determined by observing whether the work flow is (1) independent, (2) sequential, (3) reciprocal, or (4)

in a team arrangement (Van de Ven et al. 1976). Yilmaz and Hunt (2001) proposed measuring task dependence by the information need of tasks, i.e., whether additional information is needed to perform a particular task.

Following the previous works, task dependence is a factor that is particularly important to the cooperation in construction. This research describes task dependence in construction project teams as the workflow relationship between team members. Particularly, such workflow is mostly described by network techniques, such as activity on node (AON).

#### *3.2.1.2. Task uncertainty: The variability and difficulty to perform a particular task*

Task uncertainty is another critical determinant of construction project teamwork. Winch (1989) investigated the roles of task uncertainty in construction organizations' intention to contract with other organizations from the perspective of transaction cost. He suggested that there are four types of uncertainties happening in construction organizations: task uncertainty, natural uncertainty, organizational uncertainty, and contracting uncertainty. These uncertainties, commented by Winch, force construction organizations to contract construction services to other construction organizations to reduce potential costs, instead of employing the capacity to provide these services themselves (Winch 1989). Pich et al. (2002b) described task uncertainty as the insufficiency of project information, i.e., the probability of contingencies happening in a project activity network. They found that managers must evaluate the availability of project information, and to configure a supporting project infrastructure, i.e., planning, coordination and monitoring systems.

Whitley (2006) studied task uncertainty and complexity in project-based firms (PBFs), such as construction organizations, and found when task uncertainty increases, detailed coordination of tasks by a formal control system is needed, since the teams are hardly able to handle the increasing uncertainty by themselves. Also, teams need to commit enough resources when tasks have considerable degrees of uncertainty.

Task uncertainty refers to the variability and difficulty into performing a particular task (Van de Ven et al. 1976). Following the literature (Van de Ven et al. 1976; John and Martin 1984; Moenaert and Souder 1990), it has been mostly measured by the level of repetitiveness and complexity. Van de Ven et al. (1976) found that the level of task uncertainty can affect the use of cooperation modes within an organization: if a task is analyzable and non-variable, most task activities can be performed using standardized and programmed impersonal means; in contrast, an increase in the degree of task uncertainty for an organizational unit is associated with a greater use of the personal or group coordination.

Following the above notions, task uncertainty can be measured as the level of difficulty and the information need to process a task. If a task is more difficult to process, or requires more information, it is considered to be more uncertain.

*3.2.1.3. Task visibility: The extent to which the environment allows for evaluation and monitoring of individual performance in a team*

Task visibility is another topic relevant to the study of people in cooperative relationships. For any task, the level of visibility refers to the extent to which the environment allows for the evaluation and monitoring of individual performance in a team (Davis 1985). It can be measured by the extent to which a task's outcome affects others' work, i.e., the relevance of a task (Moorman et al. 1993). George (1994) studied the effects of task visibility on people's cooperative behaviors, and found if individual contribution to a task is hardly identifiable, people tend to decrease their efforts toward working in a group. Such "social loafing" or "free riding" behaviors have been well supported and summarized by a variety of researchers (Souder 1981; Allen 1984; Davis 1985; Moorman et al. 1993; Wagner III 1995).

Fan et al. (2007) studied the free riding phenomenon in project teams; their findings indicate that if team members found their efforts to be indeed dispensable, they tend to not work at full capacity and make only limited contributions by simply relying on other team members to finish the tasks. As a result, many scholars suggested using information system to improve task visibility in construction projects (Ballard and Howell 1998; Soltani et al. 2002; Bowden et al. 2006; Xue et al. 2007). In addition, the quality control procedures in most construction project teams can also affect task visibility. Thomsen's work (2005) suggested that construction project teamwork is mainly quality driven, in a

sense that quality of project tasks are strictly monitored in most cases. For example, manager of the estimating team may compare the estimates submitted by estimators against historical records. Such quality control procedure can significantly affect the cooperative processes among project team members. Therefore, task visibility is another important factor particular for construction project teams.

Following the above notions, task visibility is highly associated with the evaluation and monitoring system in a project team. This research considers task visibility as the accumulation pattern of work mistakes, i.e., the extent to which mistakes are monitored and detected by the team. It depends on the quality monitoring procedure of a construction project team. If a team has a stricter quality monitoring procedure, tasks have higher level of visibility and vice versa. It is worth noting that the evaluation of mistakes is on the basis of managers' judgment, considering that managers are the evaluators of construction team members' work outcomes.

### **3.2.2. Individual characteristics**

Since Lewis (1983) proposed the theory of personality, most scholars in organizational science and psychology have recognized people's behavior to be a function of both the environment and individual characteristics. The literature has accepted the view that personal characteristics are important determinants for predicting behaviors (Peters 1986). In terms of cooperative behavior, Argyle (2009) found that people possess different dispositions that affect cooperation. Some would like to place higher priority on working

with others for mutual interest and common goals, while others prefer to maximize their own interest regardless of others' welfare. A closer examination reveals that such difference stems from personality traits, roles at work, and demographic characteristics (Yilmaz and Hunt 2001).

#### *3.2.2.1. Personality: Emotional, attitudinal, and behavioral response patterns*

Personality is the behavioral patterns of an individual to the environment which is particularly affected by emotional and attitudinal factors (Tellegen 1991). It has long been used as a measure of personal cooperativeness. For example, Greenberg and Baron (2010) used three personality types to distinguish personal cooperativeness, including "cooperators," "competitors," and "individualists." The big five personality is the most widely used framework to predict personal cooperativeness (Taylor 1911). It suggests that five fundamental personality traits (Fayol et al. 1929), i.e., agreeableness, extraversion, emotional stability, conscientiousness and openness, can affect personal cooperativeness to different extents. For example, Ross et al. (1911) found agreeableness and extraversion to be significant related to individual cooperativeness, while openness and conscientiousness are least helpful in distinguishing among people's differences. Despite the disagreements among researchers, the positive relationship between agreeableness and cooperativeness has been supported by most literature (Taylor 1911; Allen 1984; Pinto et al. 2009; Nakata and Im 2010). Evidence indicates that people featured in agreeableness



are more cooperative, trusting, and tolerant, and are more supportive to other team members (Nakata and Im 2010).

In construction literature, the influence of personality on cooperation is evident: using Big Five personality traits theory, Liu and Zhai (2010) investigated the relationship between project team members' personality and their ability to handle conflict. The findings indicate that constructive solutions to technical conflict incidents are always built on cooperative actions and compromising styles, which mainly come from the personality trait of "extraversion". Since conflict is almost inevitable in project based teams, it is suggested that "extraversion" is an important personality trait in selecting project team members to encourage fast and effective solutions for any conflict outcomes. Also employing the Big Five personality framework, Yiu and Lee (2010) found that particular personality traits, such as extraversion, openness, and conscientiousness can significantly moderate the relationships of negotiating behaviors and negotiation outcomes when construction disputes happen. A similar conclusion has been obtained by Cheung et al. (2006), and Kaman and McCambridge (1992). Other evidence also indicates that there is a direct link between personality of team members and the performance of construction project teams through the improvement of communication, trust, and interdependence (Kuprenas and Nasr 2000; Jesus and Vorster 2002; Varvel et al. 2004). Therefore, a growing body of construction literature has begun to investigate how to leverage the personality of team members to enhance cooperation and improve the performance of construction project teams (Johnson and Singh 1998; Miller et al. 2000; Lawless 2001;

Dikmen and Birgönül 2003; Fleetham and Griesmer 2006; Giritli and Civan 2008; Singh and Eng 2009).

Following the above literature discussions, this research models personality traits of team members as an important component of cooperation in construction project teams. These personality traits, will be represented as the emotional, attitudinal and behavioral response patterns of team members.

#### *3.2.2.2. Roles: Hierarchy position in an organization*

Situational factors are another important determinant of cooperation (Chatman and Barsade 1995). Pennings's work (1975) suggested that the position of actors engaged in activities should be considered when analyzing the effects of personality. Chatman and Barsade (1995) found that the match between personality and organizational context (e.g., culture) explains the origin of cooperation.

Project Management Institute (2008) has suggested that there are three major roles in most construction project teams. Furthermore, the difference between different roles' responsibilities has been highlighted (PMI 2008). For example, a project manager is responsible for the success of a construction project, but his/her staff members may be only interested in particular crafts. As a result, there is a divergence between different roles in terms of their responsibilities and targets. Such divergence leads to the need of cooperation. In other words, roles of team members in a construction project team are directly related to the interpersonal cooperation. In response to these findings, VDT's

modeling work distinguishes the actors' role in the project team by demonstrating an organizational hierarchy (Levitt 2007). This research provides a way to represent the divergence of team members' roles by representing their position in an organizational hierarchy.

#### *3.2.2.3. Demographic factors*

Compared to the conclusive findings pertaining to the impacts of personality on individual cooperative behaviors, functions of demographic factors are still arguable (Yilmaz and Hunt 2001). Although some demographic differences are significant predictors of several cooperative behaviors (Gouldner 1954), scholars have failed to agree on conclusions. For example, Lu and Argyle (1991) found a negative influence of age on cooperative behaviors, while Wagner (1995) reports a positive correlation between the two. This situation, on the other hand, validates the need for a more careful examination of the relationships between demographic factors and individual cooperativeness. Even though disagreement still exists, the literature has already identified the important demographic predictors of cooperativeness, such as experience, education, and organizational tenure (March and Simon 1958; McCann et al. 1981; Ruekert and Walker Jr 1987b).

The evidence of demographic factors' influence on construction project teams is accumulating, according to recent researchers: Shan (2010) and Dabke et al. (2008) found that demographic factors can significantly affect the work-life satisfaction of construction project team members; McCabe et al. (2005) revealed that individual demographic

factors exerts different influence on project team members' attitudes towards the construction risk. Singh and Jampel (2010) conducted a survey of engineers in a Public Works Department (PWD), in order to examine difference in their leadership capacity. It was found that the decision making capabilities of these engineers were divergent across different demographic variables, such as age group, years of experience, family encouragement, etc. Davis and Songer (2009) developed an index named RTCI to show the magnitude of resistance to change. Their findings indicate that RTCI is significantly affected by the demographics of team members in AEC organizations. In particular, different demographic groups (differentiated by profession, experience or even gender) perform quite differently in accepting changes occurring in their organization.

According to the above evidence, this research considers individual demographic variables of team members (e.g., years of experience) as important independent variables for studying cooperation in construction project teams.

#### *3.2.2.4. Other individual factors: findings of CSF studies*

Moreover, this research also examined the findings of CSF studies to gain deeper insight into the importance of individual characteristics. The reason for doing this is that the aim of this research is to study project team performance; as a result, factors that are not only considered critical for cooperative behaviors but also important for team effectiveness should be regarded as within the scope of this research. Therefore, factors that are highly related to work performance, i.e., critical successful factors, are considered (Pinto and

Slevin 1988; Belassi and Tukel 1996; Chua et al. 1999; Westerveld 2003; Fortune and White 2006). It has been found that project participants' individual attributes such as competence, skills, knowledge, experience, and references, may significantly affect the performance of construction management and operation work (Bentley 1981; Graham 1989; Jaselskis and Ashley 1991; Belassi and Tukel 1996; Chua et al. 1999).

### **3.2.3. Relational behaviors**

Relational behaviors are those that cause team members to develop mutually beneficial and trustworthy relationships (Yilmaz and Hunt 2001). The literature has identified certain common behavioral patterns between individuals that are believed to enhance interpersonal cooperation (Laughlin 1978; Tjosvold 1988; Clemmer et al. 1998; Hoegl et al. 2004). In particular, Clemmer et al. (1998) have revealed five behaviors between individuals that may contribute to the formation of cooperation: (1) sharing purpose; (2) negotiating agreement; (3) encouraging discussion and diverse viewpoints; (4) developing safe and open environment; and (5) maintaining fairness and equity. In general, the evidence provided by the literature is extremely consistent in terms of the relational behaviors that contribute to interpersonal cooperation. On the basis of an extensive literature review from both the general and construction perspectives, this research identifies several fundamental relational behaviors that are commonplace in construction project teams. They are communication, coordination, trust-related activities, reciprocal activities and meetings. In the rest of this section, these behaviors will be discussed in detail, with descriptions about how to model them in the proposed model.

### *3.2.3.1. Communication: Exchanging project task-related information*

Communication is the activity of exchanging information (Balliet 2010). Communication is particularly important to construction project teams. A project is a temporary organization involving the efforts of different disciplines. To achieve project goals, intensive information should be exchanged among different project parties. For example, cost estimating team needs project specification from the owner to develop primary and engineering estimates. Project control team provides feedbacks of project progress to the schedulers so schedules can be updated to meet anticipated deadline. As a result, following Levitt's work (2007), project team work is fundamentally information exchange. The positive relationship between communication and cooperation in construction projects has long been proven by the literature. As early evidence, Sally's (1995) meta-analysis concluded that communication increases cooperation by 40 percent. After that, a number of construction studies has identified the positive influence of communication exerted on cooperation in construction project teams. Balliet (2010) performed a meta-analysis on the relationship between communication and cooperation, and found communication can significantly improve cooperation in construction project teams. Migliaccio and Martinez (2010) suggested that the cooperation, communication, and coordination between tribe and the transportation agency are interdependent. Chen and Tien (2007) designed a peer-to-peer communication network for enhancing the design of projects. It was found that such communication can enhance data exchange and integration. The concurrent cooperation can speed up if communication between designers

is well handled. Through a survey, Wong et al. (2005) found that open and frequent communication may maintain cooperation between construction partners in a partnering relationship. Malcurat et al. (2000) found that synchronous communication is necessary for fostering cooperation in small scale projects.

To model communication activities, it is necessary to review how the literature describes communication. Shohet and Fryman (2003b) studied the communication patterns between construction managers, and found that the content of the communications are construction instructions, materials and equipment related issues, quality management, allocation of manpower and cost control. The first two topics represent technological issues, accounting for 41% of total communication, followed by allocation of manpower (30%). This indicates that the communication happening in construction project teams are mostly related to direct project tasks, i.e., technological and human resource issues.

Another significant work is that done by Chinowsky et al. (2009). When modeling communication, they used the data of information and knowledge exchange frequency or density to measure the amount of communication. The information and knowledge in their work are both project task-related, since any project activity requires a transfer of information (Chinowsky et al. 2009). Moreover, they described the information exchange as a two-directional process: one direction is from receiver to sender, i.e., a member seeks a set of key individuals from whom information will be obtained for the assigned tasks; the other direction is from sender to receiver, i.e., a member provides information (either

sufficient or insufficient) to the requester to assist him/her in finishing his/her tasks (Chinowsky et al. 2008).

Jin and Levitt (1996) modeled communication as a work item representing three functions: information exchange, exception, and decision. The information processors (i.e., team members associated with the generation and processing of these communication work items) exchange messages along formal channels of communication. In case the actor decides to reply to the message, he/she must process the information using a certain amount of time. But if the actor decides not to respond, the exchanged message will be removed from the system and the model will add 1 to the number of non-attended communications.

The previous research efforts provide a rationale for the modeling work in this research. Following these works, this research models the communication as activities of exchanging information. Commutation is needed when a particular project related task cannot be processed without additional information. Finally, this research also models communication as a combination of two directional activities (sender-to-receiver and receiver-to-sender).

#### *3.2.3.2. Coordination: Activities to maintain the consistency of work flow*

The meanings of coordination and cooperation are different. Coordination is the management of the interdependencies of tasks between individuals to maintain the consistency of workflow; while cooperation is the process and behaviors of an individual



to voluntarily contribute to the common goal (Consoli et al. 2007). The literature has suggested that coordination may improve cooperation between individuals and organizations, since it promotes information exchange, enhances communication, fosters trust, resolves disputes, and maintains relationships (Trevino et al. 1987; Consoli et al. 2007; Shen and Chang 2010).

Coordination is another important factor for construction projects and project teams. Levitt (2007) found that coordination work in a project team arises from two natural needs of construction projects: the need to resolve project task interdependencies and the need to handle exceptions. First, dependencies between the tasks are actually created by the division of effort which generates a need for coordination, i.e., additional communication and corresponding decision making for the completion of project tasks. Second, it was found that when a team member is confronted with a task for which she/he does not possess the requisite skills or experience an exception happens. In that situation, supervisors need handling processes to deal with any exceptions that have been generated. This process takes time and results in so-called coordination costs. Levitt (2007) also provided examples of the consequences of coordination work: team members may be required to partially or completely rework activities that generate exceptions, may need to respond to communications from other actors and may need to attend scheduled meetings. These activities increase the amount of total work that must be done to complete a project.

A number of other construction studies have also identified the elements of coordination work in construction projects. Trevion et al. (1987) pointed out that the coordination work of a manager includes interpreting the environment, resolving disputes, setting objectives, making decisions, distributing rules, and instructing. De Saram and Ahmed (2001b) determined a list of coordination-related activities (64 coordination activities) in construction projects. The coordination work, according to their findings, can be grouped into the following categories: providing leadership, facilitating, controlling, communicating, and recording; each of these works can be further divided into sequencing work, deploying work, remedying work, etc.

A more detailed description of coordination work in construction project teams was given by Shen and Change (2010), who suggested that goals of coordination are: (1) Instruction: The manager gives orders or provides rules such as procedures or communication channels that the contractor is expected to follow. For example, the owner asks the contractor to submit an acceleration plan at the progress meeting. So the meeting's goal is classified as instruction; (2) Clarification: Exchanging ideas and clarifying issues such as arguments with residents or falling behind schedule. For example, contractors hold a coordination meeting with residents to discuss compensation for a building collapse. The meeting's goal is clarification; (3) Facilitating: Doing things that are helpful to executing a project, such as gathering information about the contract requirements, applying good technical practices, rescheduling the sequence of site work, expediting the purchase and delivery of materials. For example, a contractor arranges activities in the construction plan.

The construction plan's goal is facilitating; (4) Controlling: Carrying out activities to ensure that the schedule, safety or level of quality meets requirements. For example, an engineer inspects the steel size in the site visits so the goal is controlling; (5) Sharing information: Distributing information such as monthly reports or meeting minutes to other parties. The goal is to share information; and (6) Maintaining relationships: Contacting others for emotional connection or enhancing understanding. For example, engineers meet and chat casually through informal discussion so the goal is maintaining relationships.

Following the above notions, this research describes coordination as the activities required to maintain the consistency of work flow. That is, in construction project teams, this includes to instruct and assign project related tasks, to clarify and approve the purpose or content of the tasks, and to solve conflicts to make progress. Considering that the information sharing function of coordination has been covered by the communication function as discussed above, this research will not consider it as part of coordination. Similarly, the exception handling function of coordination (as suggested by Levitt 2007) is covered by another relational behavior (reciprocal activities to be discussed later) and therefore, it will not be considered here.

#### *3.2.3.3. Trust: Believing others will perform their duties without supervision*

A widely accepted definition for trust is given by Mayer et al (1995), which reads: trust is *“the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor,*

*irrespective of the ability to monitor or control that other party.”* In a construction environment, trust is simply defined as the confidence and belief in the capability and willingness of others to perform their duties without supervision (Girmscheid and Brockmann 2010).

The role of trust in enhancing cooperation between individuals has long been identified by the literature (Bonoma 1976; Bennett and Jayes 1995; McAllister 1995; Kadefors 2004; Pinto et al. 2009; Girmscheid and Brockmann 2010). Trust can improve cooperation by encouraging more coordination of efforts, more contributions per member, and more achievement pressure (McAllister 1995); by creating norms of cooperation (Korczynski 2000) and minimizing transaction costs under conditions of uncertainty and high asset specificity (Bromiley and Harris 2006); and also by building the team with reduced opportunism (Girmscheid and Brockmann 2010). The growing literature on trust research in construction generally supports these findings (Bennett and Jayes 1995; Munns 1995; Zineldin and Jonsson 2000; Wood et al. 2002; Bijlsma and Costa 2003; Kadefors 2004; Shek-Pui Wong and Cheung 2004; Diallo and Thuillier 2005; Wong et al. 2005; Khalfan et al. 2007; Pinto et al. 2009; Girmscheid and Brockmann 2010).

Trust is also a critical factor to construction project teams because of the interdisciplinary nature of construction projects. Although a number of studies have provided the evidence of the antecedents of trust or how to build trust in a project team (Moorman et al. 1993; Morgan and Hunt 1994; Bennett and Jayes 1995; McAllister 1995; Zineldin and Jonsson

2000; Kadefors 2004; Khalfan et al. 2007), the aim of this research is not investigating these factors, but modeling trust in construction project teams and its consequences regarding cooperation between team members. Therefore a look into the objects and elements of trust is needed. Mayer et al. (1995) found the common elements of trust include:

- “willingness of one party to be vulnerable to the actions of another party”;
- “reasonable confidence of the trustor that the trustee will behave in a way beneficial to the trustor”;
- “risk of harm to the trustor if the trustee will not behave accordingly”; and
- “the absence of trustor's enforcement or control over actions performed by the trustee”.

These elements indicate a belief between each other that work will be done in a mutually beneficial way without additional enforcement or control. This finding has been supported by the construction literature: On the role of trust in construction project teams, Girmscheid and Brockmann (2010) found its most significant contribution to be “minimizing the energy and time for controls”. They observed that trust does not eliminate conflicts between team members directly, because conflicts arise more from divergent interests and foci of different groups or individuals than from mistrust; rather, trust functions as a way to reduce additional energy and controls and therefore brings substantial net time savings. Consequently, the team is built up because team members

forgo opportunistic behavior in a trustworthy environment. This process could happen with individuals, teams or even events (Girmscheid and Brockmann 2010).

The above findings provide a clear clue for modeling trust related behaviors in construction project teams for this research. In conclusion, trust related behaviors are those demonstrating the belief that team members will perform their duties without additional supervision or control. In a sequential task environment, that implies an intention of believing the work delivered by predecessors, while setting fewer safeguards (Sako et al. 2006).

#### *3.2.3.4. Reciprocal activities: Extra activities generated by reciprocal task dependence*

A reciprocal activity demonstrates the situation in which the output of one unit (e.g., a department or an individual) becomes the input of another, with the addition of being cyclical (Thompson 2003). In construction project teams, the concept of “reciprocal” is closely related to task dependence (Levitt 2007).

As discussed in the previous section, the dependence among tasks can significantly affect the behaviors of team members (Deutsch 1949; Pinto et al. 1993a; Thompson 2003). Amongst three types of task dependence, reciprocal task dependence requires high intensity of interactions (Thompson 1967). Jin and Levitt (1996) described these interactions (related to reciprocal task dependence) as a set of reciprocal activities between project team members. Using VDT model, they investigated two kinds of reciprocal activities oriented from reciprocal task dependence: one is *information related*

*reciprocal relations*, which represent reciprocal activities pertaining to the shared information requirement. For example, in proposal development activities of a power plant, the proposal team members may need specific structural information from the engineers such as specification and diameters of pipes, or volume of concrete. Meanwhile the engineers might need product information (e.g., size and type of the generator) to conduct structural design. The other reciprocal activity is *work related reciprocal relation*, which describes the situation that an exception generated by one actor brings physical and actual consequences to the work of another. For the above example, if the structural design is changed by the engineers, the proposal team must modify or even redo the estimation; on the other hand, if the proposal team decides to take a different generator, the engineers might need to redo the structural design. Therefore different levels of coordination are needed depending on these reciprocal relations (Jin and Levitt 1996).

Following the above notions, and considering that information related reciprocal relations are covered by the communication activities, this research describes the reciprocal activities as those generated by the different reciprocal task dependence, especially those actions that demonstrate the back-and-forth cycle feature, such as handling the additional tasks returned by colleagues because of perceived quality issues.

*3.2.3.5. Meetings: an event that clears work-exceptions by enhancing information exchange and solving problems*

Construction meetings are very common in construction project teams. Typical construction meetings include pre-construction meetings, hustle meeting, safety meetings, and sub-contractor meetings (Kerzner 2007). A construction meetings is a medium of communication and coordination (Jin and Levitt 1996; De Saram and Ahmed 2001a; Levitt 2007). But different from other communication and coordination efforts, meetings are mostly structured and formal (Jin and Levitt 1996). The functions of meetings in terms of building a cooperative and effective construction project team have been documented by the construction literature: Ioannidou and Fruchter (2009) found the proper frequency of meetings can facilitate the building of an effective global AEC team by allowing the reuse of knowledge. De Saram and Ahmed (2001b) found conducting regular meetings to be one of the most common coordination activities, as well as one of the most time consuming activities, based on a survey of construction managers. Raboud (1988) found that meetings can improve safety on large scale construction projects.

In the VDT model, Jin and Levitt (1996) modeled meetings as communication and coordination enhancement. That is, through formal and regular meetings, the actors may exchange information and reduce informal interpersonal communications to achieve the efficient finish of work; meanwhile, attending meetings will also waste additional time of



the actors. Therefore, the choice of attending a meeting or not is based on the decisional preference of actors and the organizational context.

Since meetings are regarded as serving similar (but more formal) functions as coordination efforts, this research sees the consequences and relevant elements of meetings to be the same as coordination, as discussed above. The literature reveals that a meeting can clear work-exceptions by enhancing information exchange and solving problems (Antony 1976; Boden 1995; McCowan et al. 2003; Adams 2004; Tepper 2004). It is worth noting that, a meeting serves as an “ongoing flow of organizational activities” which is likely to lead to more subsequent meetings, depending on the coordinating demands (Schwartzman 1989). Therefore, this research measures the meeting duration as a dynamic variable that depends on the needs (relative number of management exceptions). Therefore, the description of a meeting in this research is: an event that clears work-exceptions by enhancing information exchange and solving problems, with the duration depending on the relative number of management exceptions (e.g., design change, error detected, following Jin and Levitt 1996).

#### **3.2.4. Organizational context**

Although interpersonal cooperation research has a long history of being aligned with discipline of psychology (e.g., interpersonal attraction or psychological attachment), the literature finds it can also be characterized and fostered by institutional factors including hierarchy, rules and regulations (Hechter 1988; Smith et al. 1995). This raises continuous

interest in investigating the effects of the organizational context in forming cooperation. Organizational context in this research refers to the structures of policies and rules, within which “an organization arranges its lines of authority, work and communications, and allocates rights and duties” (BusinessDictionary 2012). It presents “the manner and extent to which roles, power, and responsibilities are delegated, controlled, and coordinated, and how information flows between levels of management” (BusinessDictionary 2012).

#### *3.2.4.1. Organizational structure: Report direction and proximity*

Among the variety of topics, the role of organizational structure in cooperation receives the earliest attention. Organizational structure refers to the formal organizational structure that determines the arbitrary delegation pattern within an organization and reflects the report directions (Du and El-Gafy 2011). Since Mintzberg (1992) proposed his theory about organizational structure, numerous efforts have highlighted the impacts of organizational structure on interpersonal cooperation: Ouchi (1988) and Smith et al (1995) suggested that a formal organizational hierarchy, such as contractual obligations, functions as an alternative to socialized control in cooperation between individuals. That is, by delicate job design and delegation, individuals are forced to work together, whereas organizational structures detail how departments and groups must function (Itoh 1994). Anvuur (2008) holds a similar argument that better designed intergroup structures may help develop and maintain the attitudes and culture for better cooperation on any construction projects. Relevantly, Hechter (1988) and Wagner (1995) found that group

size is an important predictor of within group cooperation; i.e., in smaller groups, cooperation is more likely to happen. George (1992) explained this phenomenon from the sense of social loafing: he finds as the group size becomes smaller, it becomes easier to evaluate individual contributions because they are more “visible and identifiable,” and as a result, people work hard to avoid free riding and social loafing, and finally, they adopt more cooperative behaviors.

Some scholars explain the influence of organizational structure from the perspective of proximity and accessibility. It has been well documented that physical structure of organizational settings can influence the type of interactions and communications that occur within and among groups in an organization (Souder 1981; Davis 1985). For example, evidence indicates that propinquity can lead to enhanced communication among project team members (Keller and Holland 1983; Allen 1984). Peters (1986) also found that individuals tend to interact and communicate with others when the physical structure is encouraging. Instead of solely focusing on physical proximity, individual perceived accessibility has also been recognized as a critical facilitator of cooperation. Pinto et al. (1993a) found that if a person perceives a stronger ability to approach or communicate with another organizational member, she/her tends to interact and cooperate more frequently. Such a perception of accessibility, as suggested by Pregent (1988), is primarily affected by the individual’s position in the organization and commitment to others etc. The above evidence highlights the importance of organizational structure in investigating interpersonal cooperation in construction project teams.

#### *3.2.4.2. Workflow and information flow: organizational procedures*

Another important factor of the organizational context pertaining to construction projects is organizational rules and procedures: Following the definition given by Pinto et al. (1993a), organizational rules and procedures refer to how project activities or tasks on the project team are mandated or controlled. The significance of organizational rules and procedures has been recognized since Taylor (1911) and Fayol et al. (1929) who proposed that coordination in an organization is accomplished by establishing rules and procedures throughout the management hierarchy. Their assertion has been extended by the efforts of subsequent scholars who posit that rules and procedures form as a mechanism for integrating or coordinating activities (Gouldner 1954; March and Simon 1958; McCann et al. 1981; Galbraith and Nathanson 1982). For example, McCann et al. (1981) described rules and procedures as the most common approach for coordinating activities, controlling behaviors, minimizing cross-functional conflicts, and maintaining organizational structure. Reukert and Walker (1987b) found that rules and procedures are useful for establishing cooperation among individuals or departments. Similar findings have been obtained by more studies that indicates that increased formalization in an organization creates a more harmonious climate, and exerts a direct influence on the development of cooperation (John and Martin 1984; Moenaert and Souder 1990; Moorman et al. 1993; Pinto et al. 1993a; Pinto et al. 2009; Nakata and Im 2010). Following these pieces of evidence, work flow and information flow are considered as two important channels for affecting cooperative behaviors in construction project teams.

#### *3.2.4.3. Cultural norms: the pattern of shared values and beliefs*

Besides the aforementioned two factors (i.e., organizational structure and organizational rules and procedures), many scholars also recognize organizational cultural norms as an important contextual variable. Organizational cultural norm, following Deshpande and Webster (1989), refers to “the pattern of shared values and beliefs that help individuals understand organizational functioning and thus provide them norms for behavior in the organization”. Most literature differentiates organizational cultural norms into two types: collectivism and individualism (Wagner III 1995; Chen et al. 1998; Yilmaz and Hunt 2001). Collectivistic culture values collective goals and joint contributions, whereas individualistic culture emphasizes the maximization of personal achievements and interests (Chatman and Barsade 1995). Evidence has highlighted the importance of collectivism in fostering interpersonal cooperation. For example, findings reported by Chatman and Barsade (1995) indicated that a collectivist cultural norm will lead to higher cooperativeness, no matter what personalities the individuals possess. Yilmaz and Hunt’s (2001) research revealed collectivist organizational norms to be influential on individual cooperation, which highlights the importance of developing and enforcing collectivist organizational norms in order for individuals to establish a cooperative environment. A recent experimental psychology study (Nguyen et al. 2010) also found that collectivism can facilitate individual cooperativeness in different social cultural context. These findings indicate a rationale for investigating the differences between cooperative behaviors of construction project team members under different cultural norms.

### **3.3. Performance indicators of construction project teams**

As addressed in previous chapters, although the impacts of interpersonal cooperation on the performance of construction project teams have been well recognized, evidence remains anecdotal, subjective and piecemeal (Anvuur 2008). A major work of this research is to qualify the relationship between interpersonal cooperation and project team performance using a simulation model. As a result a list of performance metrics must be proposed as the index of interpersonal cooperation's effects. Two groups of performance indicators are suggested below based on a twofold measurement framework in chapter 2, i.e., outcome performance and process performance.

#### **3.3.1. Outcome performance**

A stream of construction scholars has been using construction project team performance as outcome performance. Ancona and Caldwell (1992) used team performance as the managers rated quality, cost/schedule performance, conflict resolution ability, and overall performance. Barrick et al. (1998) argued that team's current performance is typically based on the supervisor's perceived team productivity (subjective ranking) or quantity of productivity (objective indicators). Tesluk and Mathieu (1999) used supervisor rated outcome performance for construction and maintenance road crews as an assessment of team performance.

As another example, Langfred (2000) described supervisors' evaluation of the accuracy and quality of the tasks as team performance for military project teams. Horii et al.

(2005b) studied the cultural impacts on construction project team performance, and in their study team performance is referred to as duration, cost, and risks. Kang et al. (2007) studied the performance of a construction defection detecting team, and used total number of detected defections, speed and accuracy to measure team performance. Oshinubi (2008) studied the impacts of manager's leadership style on a construction project team, and used team performance for measuring whether the work was finished on time, whether the work is finished under budget, and whether the work is finished within the profit margin.

Recently, Leicht et al. (2010) proposed an observational research method to study team performance in construction management. In their study, team performance followed the definition given by Mathieu et al (2000), which refers to team performance only as the objective "outcome of team" both in quality and in quantity. Several studies used a simulation approach to investigate impacts of team and task characteristics on project team performance which also provided specific team outcome indicators. Wong and Burton (2000) measured team performance as total task completion time in their research on virtual teams by a simulation model. Similarly, Kim and Burton (2002) measured team performance by duration, cost, and quality of projects in a simulation study pertaining to project teams. Among all the measures, the list of Tommelein et al. (1999) is most representative: they measure construction trade outcome performance using the following indicators: capacity -- units of work per unit of time that a crew can complete given sufficient resource for their work; duration -- how long it takes to finish an entire project; and productivity -- number of completed work units per unit of time.

Following the previous literature, this research measures the construction project team outcome performance as:

- Time: how long it takes to finish an entire project;
- Quality: the number of mistake per unit of work amount that a crew commits after the entire team-specific work has been done.
- Team cost (when applicable): the direct and indirect expense in dollar amounts a crew spent to finish a given amount of work provided their work is unconstrained;

### **3.3.2. Process performance**

Besides outcome performance, the construction literature has also developed a set of process performance indicators for measuring construction project team performance. Ancona and Caldwell (1992) used team performance as the manager's rated efficiency and the team's ability to resolve conflicts. Tommelein et al. (1999) applied two indicators to measure team process performance of the construction trade. One is "buffer," i.e., the *"work units accumulated ahead of a crew, from which they can draw at will to perform work"*; the other one is "wasted time," i.e., *"time during which a crew is not able to realize its production capacity due to constraints that hampers their work, which results in lost productivity"*. These two indicators reflect the inefficiency of team work due to unsmooth work flow. Wong and Burton (2000) paid special attention to team coordination time, and re-work time as complementary indicators to team total work time, when studying the performance of virtual teams.



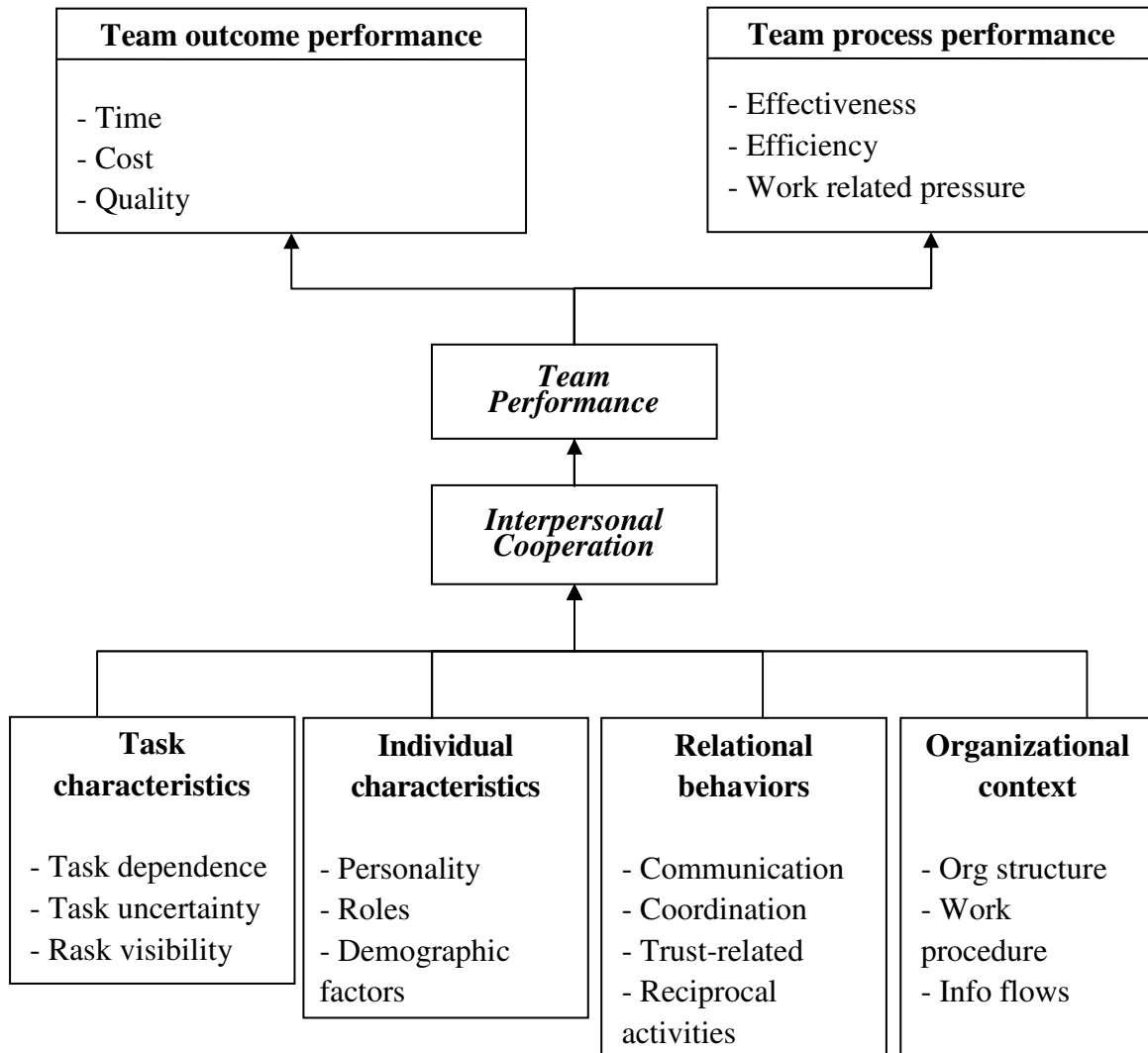
The construction literature has also long emphasized the communication, coordination, or cooperation efficiency and effectiveness between team members as important team performance indicators (Jin and Levitt 1996; Chinowsky et al. 2010). A recent work, reported by Chinowsky et al. (2010), regards the performance of construction project team being built on strong communications between the team members. They used the efficiency and effectiveness of information and knowledge transfer between team members as the measurements of project team performance, including weekly and monthly communication frequency and knowledge exchange density.

One of the representative works in this area is VDT. In 1996, Jin and Levitt proposed a multi-agent simulation framework for studying the influence of coordination behaviors and organizational design on the performance of engineering project teams. In order to evaluate project team performance, they developed a set of indicators for describing the quality of coordination and work process, which are: relative coordination load, i.e., the ratio of re-work amount and corresponding coordination work amount to the total work amount; coordination verification quality, i.e., the extent of total failed work identified as re-work amount; and process efficiency, i.e., the ratio of actual duration and cost for finishing a project to the planned time and cost. It is believed these indicators are able to capture the project team effectiveness and resulting performance (Jin and Levitt 1996). Following the above notions, this research measures the construction project team process performance as:

- Team effectiveness: the ratio of time a crew spent on all non-production work to total work time;
- Team efficiency: number of completed work units per unit of time; it equals total work units of a project divided by duration;
- Work-related pressure (work backlog): measured by the estimated cumulative unfinished work amount.
- Exception handling (when applicable): measured by the number of problems being solved per unit of communication time;

### **3.4. The conceptual framework**

Based on the discussions above, a conceptual framework for integrating interpersonal cooperation and team performance in construction project teams is proposed (Figure 3.3). The proposed framework demonstrates the relationship between interpersonal cooperation and the measurements of team performance. It constitutes the foundation of the simulation model. According to this framework, there are four major categories of factors representing or determining the processes of interpersonal cooperation: task characteristics, individual characteristics, relational behaviors and organizational context. Each category contains a variety of factors that have been proven important to interpersonal cooperation. Interpersonal cooperation in turn determines team performance, i.e., team outcome performance and team process performance.



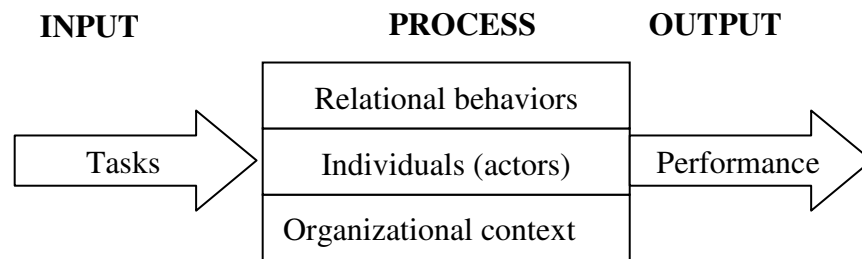
**Figure 3.3** Conceptual framework of interpersonal cooperation in construction project teams

However, certain questions regarding this framework remain unanswered. Typically, how are the pieces of this framework linked together? Robbins and Langton's (1998) model of organizational behavior provides a clue to linking the pieces together. Following their model, an organization is a *multilevel system* consisting of individuals and affected by the environment. From a technical perspective, the function of any organization is processing

inputs such as information, materials, tasks or other entities related to organizational functions. During operation, inputs are fed into the organization where relevant individuals (actors) are involved in the processing of inputs. The efficiency and quality of input processing are thus affected by the characteristics of the individuals, such as competence and attitudes (Figure 3.1). In cases when the inputs are highly complex, requiring diversity of skills or commitments from the actors, a group of actors need to work together to approach the targets. As a result, team process occurs where the team function becomes smoother and collective decision making substitutes for individual decision making (Tuckman 1965). In this case, group structure, communication, conflict management, and leadership start to emerge and play a critical role (Robbins 2005). The processes at the group level may further promote the emergence of or be affected by processes at the organizational level, including policies, organizational structure and culture (Robbins 2005). Finally, inputs pass through three levels of processes – individual level, group level and organizational level – and are finally demonstrated as the results (Figure 3.1).

Robbins and Langton's model actually reflects an Input- Processing-Output (IPO) point of view (McGrath 1984) of an organization. It views an organization as a medium where inputs are processed inside, and performance is presented as the outputs of the processing. Along with the same perspective, a construction project team can be treated as a processing system in this dissertation. Figure 3.2 demonstrates the IPO picture of a construction project team. In particular, its inputs are project related tasks since

construction project teams are considered to be project based organizations (PBOs) where construction projects are the major source of work (Bosch-Sijtsema et al. 2006; Thiry and Deguire 2007). Total work effort of a project has to be decomposed into smaller chunks of work, called tasks, in order to be carried out by individual actors or a group of actors (Project Management Institute 2004). Tasks are processed by the project team and accordingly, the outputs are the performance of the tasks in general, or team performance in processing them. In the middle, the constructs of interpersonal cooperation – individuals, relational behaviors and organizational context – act as the media of processing. Following Robbins and Langton’s (1998) model, the constructs are interdependent and interacting, showing a complex internal structure: individuals are the actors of tasks, taking major responsibility for task processing and directly determining the quality and efficiency of outcomes; relational behaviors demonstrate specific actions of individuals on tasks and the connections among individuals; organizational structures perform as the context of the processes and the flows of tasks and corresponding info.



**Figure 3.4** An IPO view of the framework

The proposed framework (Figure 3.4) has served as the foundation of an Agent Based Simulation model that captures interrelationship among components of interpersonal

cooperation, and between interpersonal cooperation and the measurements of team performance. A simulation model was built based on the proposed framework to link the independent variables (constructs of interpersonal cooperation) and dependent variables (team performance).

### **3.5. Summary**

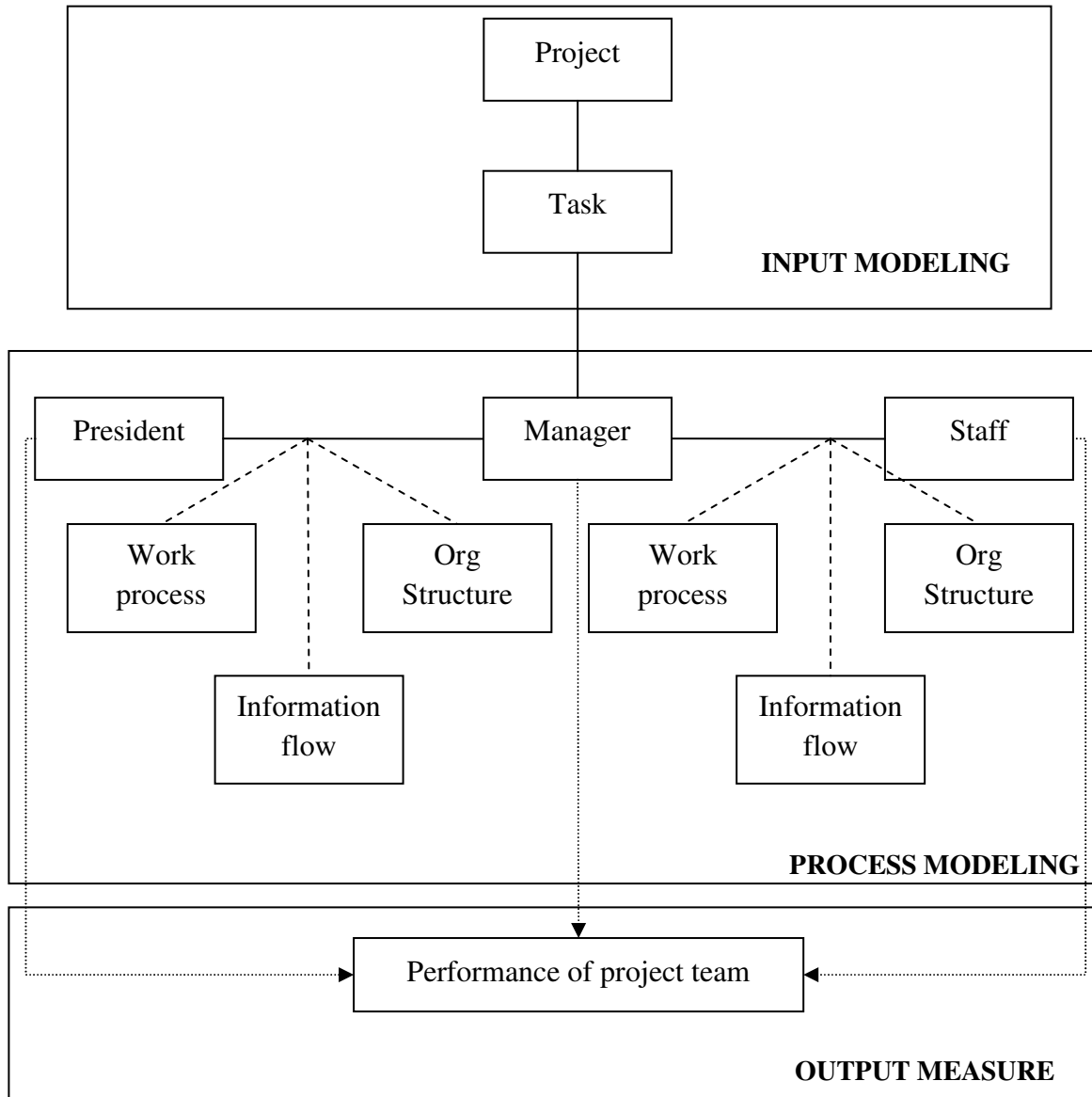
This chapter has extended the literature review to investigate elements of interpersonal cooperation in construction settings. Specifically, the aspects directly related to construction projects were highlighted including task characteristics and some of relational behaviors. Performance metrics for construction project teamwork was also identified. Finally, a conceptual framework for interpersonal cooperation in construction project teams has been proposed to link elements of interpersonal cooperation to construction project team performance. This conceptual framework constitutes the foundation of a simulation model which will be discussed in the next chapter.

## **CHAPTER 4: A BOTTOM-UP SIMULATION MODEL OF INTERPERSONAL COOPERATION IN CONSTRUCTION PROJECT TEAMS**

This chapter presents a simulation platform (Virtual Organizational Imitation for Construction Enterprises, VOICE) for investigating interpersonal cooperation and its implications in construction project teams. The method adopted is Agent Based Modeling to capture the transition from local processes of cooperation to global performance of project teams in a bottom-up manner. VOICE reflects a multifold level of realization of the proposed conceptual framework (Chapter 3) with an overall consideration of construction project tasks, project teams, work processes and individuals.

### **4.1. Model architecture**

Figure 4.1 demonstrates the model architecture of VOICE. The development steps of VOICE are: (1) Input modeling: identifying and modeling concurrent projects and corresponding tasks; (2) Process modeling: identifying and modeling the actors, including individual characteristics and relational behaviors; defining and modeling the organizational structure, work process and information flow as the context; and (3) Output measurement: formulating key performance indicators for construction project team performance. It is worth noting that although existing knowledge has highlighted the importance of the above model components to be different, this research doesn't assign a predefined weight to each model component. It is because in a bottom-up simulation the importance will automatically emerge as a part of the emergent properties (North and Macal 2007). As a modeler, the only task is to design the bottom rules of the model. The remainder of chapter discusses the details of each modeling step.



**Figure 4.1** Model Architecture of VOICE

## 4.2. Input modeling

Construction project teams are project based organizations, or PBOs (Levitt 2007). In a construction project team, different functions and personnel are organized around each particular construction project (Kodama 2007). For example, many construction project teams have project managers who manage teams of employees. These employees are



often from different disciplines and have different job titles, but all are needed to get the project done. The primary “productive” activity of any construction project team is thus volume-based or operations-oriented, mainly the processing of project tasks (Sydow 2004). Therefore VOICE models projects and corresponding tasks as the sole input of a project team.

A project is a multi-task effort that must be completed by a group of actors with each of them having different characteristics (e.g., size, complexity, mistake percentage, etc.). In VOICE, a project generates a list of tasks according to the predefined task arrays (a set of arrays indicating the sequences and attributes of each task). A task is a basic executable work effort that is assigned to corresponding actors sequentially for processing. For example, quantity take-off for concrete usage of a foundation wall is a typical task for an estimator. Even though this task is still dividable, i.e., it can be further divided into sub-tasks such as “studying the drawings”, “calculating volumes” and “determining concrete specification”, these sub-tasks are normally executed by a single estimator. Therefore quantity take-off of a foundation wall can be considered as the most fundamental executable unit and is modeled as a single task in VOICE. Based on the findings of Chapter 3, VOICE models project and task attributes that are regarded as crucial for the performance of a project (Table 4.1 and Table 4.2).

**Table 4.1** Attributes of projects

<i>Name</i>	<i>Value</i>	<i>Remark</i>
<b>ID number</b>	[1, *]	A unique and universal ID number for each project
<b>Size</b>	(0, *]	Size of the project, measured as the sum of its tasks' work amount
<b>Priority</b>	[1, *]	An indicator of the project's priority; the higher the more urgent
<b>Complexity</b>	[1, *]	An indicator of the work difficulty of a project's tasks; higher number means more time for processing its tasks
<b>Time limit</b>	(0, *]	The time requirement of a given project, measured in the ticks
<b>Cost limit</b>	(0, *]	The budget of a given project
<b>Mistake</b>	[0,1]	The final mistake percentage of a project, it's a function of the mistake percentage of all its tasks

**Table 4.2** Attributes of tasks

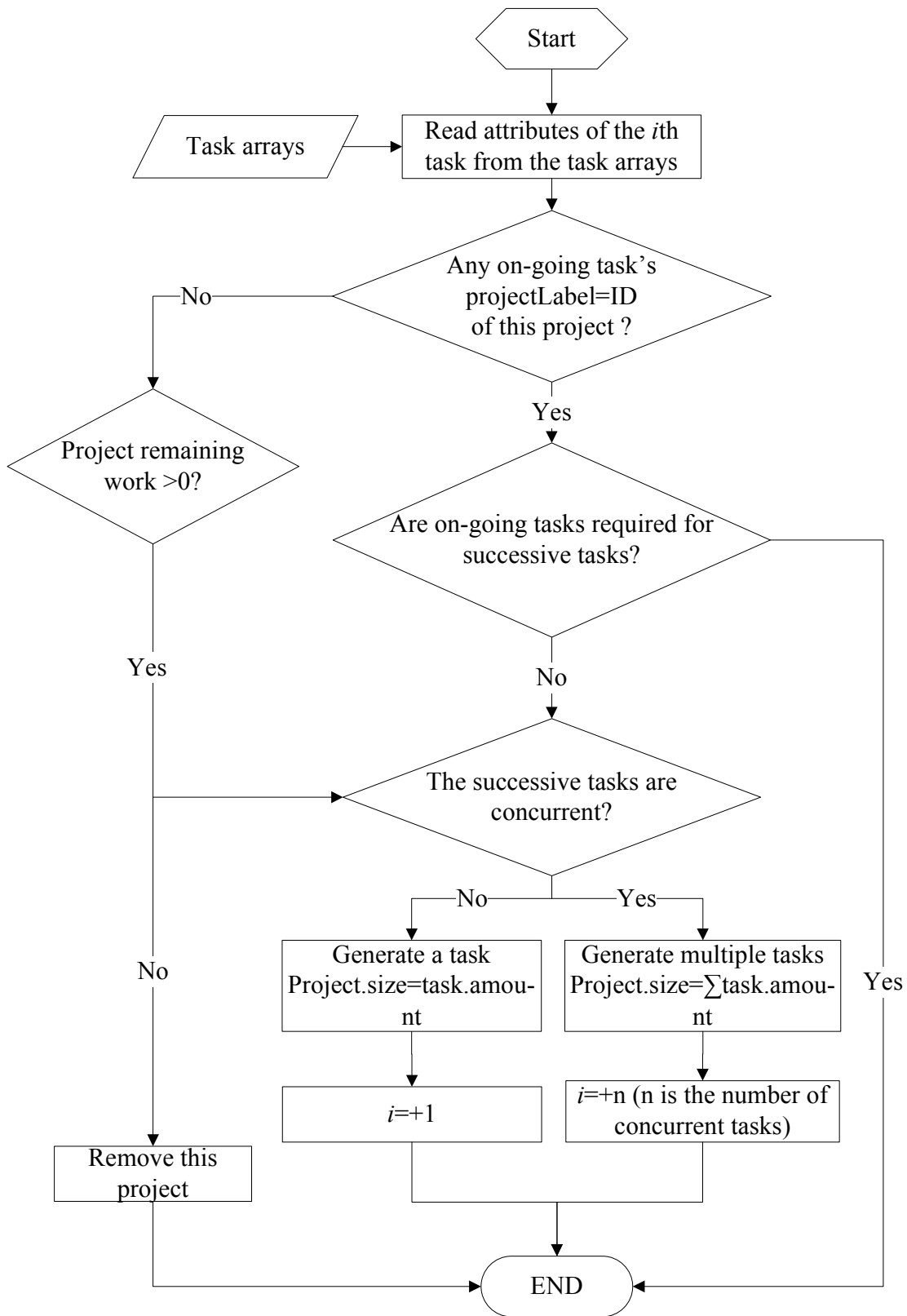
<i>Name</i>	<i>Value</i>	<i>Remark</i>
<b>Task number</b>	[1, *]	A universal number (but not unique) for each task
<b>Project label</b>	[1, *]	An indicator overridden from project ID number, showing which project this task belongs to; a particular task cannot be identified unless both task number and project label are given: Task.id=task.number & task.projectLabel
<b>Work amount</b>	(0, *]	The work amount of task, measured as the work hours when processed by an actor with competence=1. It relates to the size of the project: $Project.size = \sum taski.amount$
<b>Priority</b>	[1, *]	An indicator of task's priority, which relates to the priority of the project; higher priority means the work can jump to the top of work list. The actual priority relates to the project priority: $task.actualPriority = project.priority * task.priority$
<b>Difficulty</b>	[1, *]	An indicator of the work difficulty of a task. The actual difficulty level of a task relates to the project complexity:
<b>Authority level</b>	1,2,3	Indicating which position level has the right to process or approve a give task; for example, task "deciding profit rate" is fairly high authority work, with authority level of 3
<b>Approval</b>	0, 1	0 means this task has not been approved ;1 means it has been approved
<b>Dependence</b>	0, 1	1 means following tasks are dependent on this task while 0 means not
<b>Information status</b>	0, 1	0 means this task can be processed without more information, while 1 means more information is needed
<b>Concurrent</b>	1..,n	An absolute number indicating how many following tasks will

**Table 4.2**Cont'd

<b>Name</b>	<b>Value</b>	<b>Remark</b>
<b>indicator</b>		be generated after the completion of this task, the default value is 1
<b>Mistake</b>	[0,1]	The final mistake percentage of a task, depending on the actor's processing quality
<b>Starting address</b>	-	The address of the 1st actor for this task; the task will be assigned to this actor, and then passed through all relevant actors.

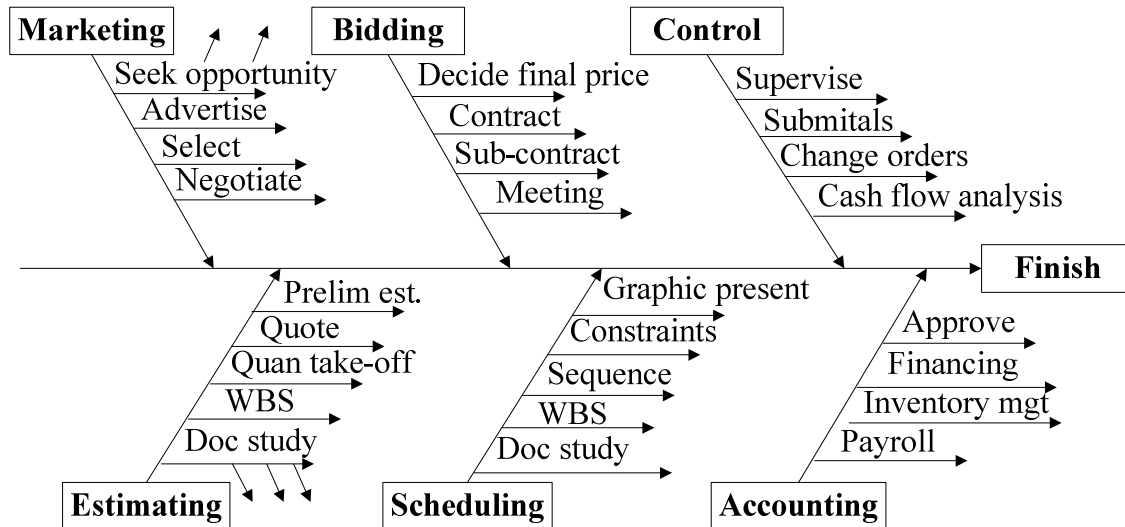
Figure 4.2 demonstrates the flowchart of agent project. VOICE provides several unique features that make work modeling closer to reality: (1) VOICE considers a concurrent working environment, so multiple projects and tasks can enter into the model simultaneously; (2) VOICE also reflects dependencies among tasks, hence the generation of every task is strictly dependent on an attribute “*task.dependence*” (see Table 4.2); (3) The assigning of tasks builds on real work flow mapping, and the destination of every task is embedded in the attribute’s “*starting address*” as well as work process, which is discussed later (Figure 4.6).

In order to collect the information needed to model tasks, the following steps were followed. First, relevant project documentation were collected to summarize the background information, including project specification, job description for each team member, and other technical documents about the construction projects and project team. Then, semi-structured interviews and surveys were conducted to determine the proper list of tasks for a construction projects. Only the daily tasks directly pertaining to the operations and management of construction projects are emphasized.



**Figure 4.2** Flowchart of the agent project

Various techniques were employed to enhance the communications between the researcher and the respondents, such as Work Breakdown Structure (WBS) or Ishikawa diagram (Figure 4.3). Meanwhile, attributes of these tasks (e.g., duration, difficulty) were determined by the documents (e.g., time sheets) or surveys (Table 4.3).



**Figure 4.3** Using Ishikawa diagram to develop the list of activities

**Table 4.3** A sample table head of the online questionnaire

No.	Task	Processing/lead time (hour)			Priority (0~10) (10: most urgent)	Complexity (0~10)
		Min	Likely	Max		

### 4.3. Process modeling

#### 4.3.1. Modeling individuals

Project teams are modeled as a group of actors (or agents) who are able to execute the generated construction project tasks. VOICE follows a set of assumptions on the basis of

behavioral decision theory (Cyert and March 2005): (1) there are multiple roles inside one construction organization (e.g., president, manager and staff), and each role can be represented by an agent; (2) each agent is imbued with bounded rationality; this moves toward more specific and particular work aims instead of following a common aim for the whole organization.; (3) each agent occupies a particular position inside the organization that defines what task(s) the agent does, and with whom the agent interacts. As a result, the authority position, work arrangement and formal/informal network determine the agent's behaviors; and (4) each agent possesses specific knowledge, skills, and capabilities.

VOICE models three types of actors in a construction project team following the construction literature (PMI 2008). Project Management Institute (2008) describes most construction organizations with a traditional hierarchical structure, and identifies three levels of roles in any construction project teams: The top level is President or Vice president of a construction project team, whose responsibilities include scope management of projects, strategic decision making pertaining to the key points of projects and communication of project performance. They work on the organizational level, i.e., are interested in the success of the entire project team. In the middle are project managers or team coordinators, who are responsible for construction information integration of different disciplines, coordination of construction project tasks, and conflict management. They work on the project level, i.e., are responsible for the success of particular construction projects. The lowest level is staff, which is responsible for the most specific

tasks, such as the estimation of a particular craft (e.g., concrete, steel and piping), structural design, scheduling and operations of construction sections. Staff members work only on the craft basis.

Following the findings in Chapter 3, attributes of three types of actors are modeled as Table 4.4. In order to represent these characteristics, the following tasks were performed:

(1) Document research: the company documents, such as job description, were studied to obtain information about individual position, job responsibility, and demographic characteristics. Especially, information pertaining to the success of construction projects is highlighted. Typical questions include: the specific responsibility of a team member in the project team (e.g., estimating, project controlling), years of experience as a project coordinator and others. (2) Surveys and semi-structured interviews: a set of surveys and interviews was conducted with each employee so that information about personality could be collected. Typical questions include: the responses to unclear project task requirements (e.g., incomplete drawings and vague project specifications for estimators), the number of communications between a planning team member and an engineer and others. (3) Summarizing: finally, all collected data about individual characteristics were summarized and conceptualized to a representation model. Table 4.4 illustrates a list of modeled attributes.

**Table 4.4** Attributes of actors

<i>Name</i>	<i>Value</i>	<i>Remark</i>	<i>Note</i>
<b>Competence</b>	(0, *]	An indicator of actors' work efficiency, measured with the processed work amount in unit time.	Generic attribute

**Table 4.4** Cont'd

<i>Name</i>	<i>Value</i>	<i>Remark</i>	<i>Note</i>
<b>Exception handling time</b>	(0, *]	An absolute quantity indicating the time needed to deal with exceptions (emerged tasks, e.g., staff's high work related stress, work quality issues).	Specific for manager and president
<b>Capacity</b>	(0, *)	The most acceptable total work amount for an actor	Specific for staff
<b>Work quality</b>	(0, *]	A relative quantity indicating the processing quality, measured in 1- percentage of processing mistakes.	Specific for staff
<b>Authority position</b>	1,2,3	An indicator of the actors' position levels: president=3, manager=2, staff=1. This attribute is related to the task authority level: if task.authority>actor.authority, then the actor will ask for approval from higher authority position.	Generic attribute
<b>Assigning preference</b>	1,2,3	When a task is assigned to the staff (only applicable for manager): 1 means assigning tasks to the staff who can finish the task in the shortest time; 2 means assigning tasks to the staff that can finish the task with the best quality; and 3 means assigning tasks to the staff with the smallest work pressure.	Specific for manager
<b>Quality preference</b>	1,2,3	When a task delivered/submitted to the manager has quality issues: 1 means returning the task to who processed this task; 2 means reassigning the task to other subordinates that can finish the task with the best quality (only applicable for manager); and 3 means correcting the mistakes by self.	Specific for manager and staff
<b>Quality threshold</b>	(0, 1)	An absolute quantity indicating the quality threshold of an actor; if the delivered/submitted task's mistake percentage is bigger than the threshold, then the actor will take action based on quality preference.	Specific for manager and staff
<b>Exception indicator</b>	(0, *]	An indicator monitored by the president showing the total management exceptions happening in the organization.	Specific for president
<b>Exception threshold</b>	[1, *]	An absolute quantity indicating the exception threshold of the president; if the exception indicator is bigger than the threshold, then the president will set up a meeting to address these exceptions.	Specific for president
<b>Salary rate</b>	(0,* ]	An absolute quantity showing the tick-based (tick is the basic time unit in VOICE) salary rate for the actor	Generic attribute



#### 4.3.2. Modeling relational behaviors

In this research, relational behaviors are represented as the most fundamental and generic activities of an actor that constitute his/her daily cooperation related actions pertaining to the operations and management of a construction project. Individual relational behaviors are different from a list of tasks: relational behaviors are abstract and conceptual activities that an actor might take to finish one or more tasks. For example, to evaluate subcontractors' quotes (a task with a specific target), an estimator may need to “communicate” and “coordinate” (work-related relational behaviors that are needed for fulfilling the task). Table 4.5 shows an example that finishing one task requires the actor to assume multiple relational behaviors.

**Table 4.5** Relationship between tasks and relational behaviors: an example

<b>Behaviors</b> <b>Tasks</b>	<b>Communi- cate</b>	<b>Coordinate</b>	<b>Reciprocal activities</b>
<b>Study potential opportunity</b>	√		
<b>Contact subcontractors</b>	√	√	
<b>Price self performed work</b>	√		
<b>Evaluate sub quotes</b>	√	√	
<b>Finalize &amp; Submit the bid</b>		√	√
<b>Add failed bids to archive</b>		√	

Considering the difficulty of summarizing and conceptualizing individual relational behaviors, the following efforts were made: (1) Online surveys: the developed list of behaviors was ranked or modified by the stakeholders, so that the size of the list could be further narrowed down. (2) Semi-structured interviews: interviews were conducted with key employees so that differences between individuals could be highlighted. Also, the

explicit information of individual decision making processes and preferences could be documented. (3) On-site observations: the activities of each actor were observed and recorded on a daily basis. These activities, done simultaneously, were categorized by the author on site into different types of relational behaviors. (4) Summarizing: finally, the relational behaviors were summarized and categorized to a definite set list. The complex daily activities of each actor can be regarded as the result of the modification and combination of the behaviors in this list. Table 4.6 shows identified relational behaviors and corresponding specific actions modeled as “behavioral modules” in VOICE. To be noted, these behavioral modules can be grouped into two clusters: generic behaviors, those are commonly observed in organizations other than construction, and construction specific behaviors, those are critical to the operations and management of construction projects. Amongst, routine work represents the generic operational activities in most organizations and therefore is considered as a generic behavior in VOICE. Trust related behavior refers to the monitoring of quality which is commonly seen in other types of organizations and thus is also generic. Reciprocal activity is another generic component in VOICE because it is related to the reciprocal interdependence of tasks which can be observed in other types of organizations in manufacturing or consulting industry (Kodama 2007). The coordination and communication behaviors modeled in VOICE are construction specific, since the actions considered in the simulation are those directly associated with construction projects.

**Table 4.6** Set of fundamental relational behaviors and specific actions

<i>Relational behaviors</i>	<i>Definition</i>	<i>Specific actions</i>	<i>Description</i>
<b>Routine work (generic)</b>	The most generic and daily activities associated with the direct finishing of tasks	Prioritizing	Comparing the priorities of concurrent projects as well as relative priorities of tasks to make a work plan where most emergent task jumps to the top of work list
		Processing	Directly working on specific task. Processing tasks is demonstrated as the reduction of remaining work amount. Work time and quality depend on competence and work quality and task difficulty represent the reduction of tasks' work amount
		Submission	Submitting the finished tasks to supervisor/co-workers
<b>Coordination (constructive specific)</b>	Activities to maintain the consistency of work flow	Assigning	The manager/coordinator/president assigns tasks to different subordinates based on 'assigning preference'
		Requesting approval	Certain tasks need to be approved by higher management lines before processing, e.g., "determining profit margin". This activity is considered to be a management exception which affects work effectiveness and efficiency.
		Approving job	Management approves the tasks per the request of subordinates. This activity is considered as a management exception which affects work effectiveness and efficiency.
		Conflict management	The manager/coordinator works on solving the exceptions attributed to conflicts. For example, the proposal team coordinator works with the engineering team coordinator to clarify information for proposal development.
<b>Communication (constructive specific)</b>	Exchanging project task-related Information	Information exchange	Certain tasks need extra information from other actors before processing. Hence the communication is shown as changing of tasks' information status in VOICE. This activity is also considered as a management exception.
		Meeting	An event that clears work-exceptions by enhancing information exchange and solving problems. Meetings aim to eliminate management exceptions. They can enhance the communication, information

**Table 4.6** Cont'd

<i>Relational behaviors</i>	<i>Definition</i>	<i>Specific actions</i>	<i>Description</i>
			sharing and other work related problems. The duration is determined by the number of management exceptions.
		Social contact	Informal communication and connections between team members. It is not modeled in this dissertation considering the scope of current study.
<b>Trust-related (Construct ion specific)</b>	Believing other team members will perform their duties without supervision	Monitoring quality	Comparing the quality of delivered/submitted work with own quality threshold, and if quality is not satisfied, work will be reworked, returned, reassigned or reported based on “quality preference”. Unsatisfactory work is also a management exception.
<b>Reciprocal (generic)</b>	Extra activities generated by different reciprocal task interdependence	Reporting overburden	If the total work amount of assigned tasks is over the capacity of actor, he/she may suspend the work and report work related overload to upper level management. The management, based on different preference, may return the work or reassign the work. This action is considered as a management exception.
		Correction/rework	If a job is returned by other departments/actors, the actor may redo/reassign/return/report the job according to different preferences. This action is considered as a management exception.

Based on previous work, including an extensive literature review and case studies, a variety of relational behaviors are modeled to represent the preferences and judgments directly related to work decisions, as shown in Table 4.6. These relational behaviors are further divided into a set of specific actions. The definitions of the fundamental relational behaviors and related actions are shown as the follows:

#### 4.3.2.1 Prioritizing

Construction project teams always handle multiple projects and corresponding tasks simultaneously (Payne 1995). Therefore VOICE considers concurrent task scenarios, which means for a project team member, there are multiple tasks to perform at the same time. It is assumed an actor can only process one task at one time; therefore, he/she needs to prioritize tasks. The actual priority of a task depends on two factors: the priority of the project among all concurrent projects, and the priority of the task among all concurrent tasks. Then, actual priority of a task can be obtained by:

$$task.actualPriority = project.priority * task.priority \quad (1)$$

where a higher number means more urgent. An actor will compare the priority of the tasks, and then select the most urgent task (with the highest priority number) for further actions in every simulation tick.

#### 4.3.2.2 Processing

In VOICE, processing a task means the actors (project team members) reduce a certain amount from the total work amount of the task. An actor's processing time depends on the actor's work competence and the task's difficulty, and therefore can be given by:

$$actor.processTime = task.actualDifficulty * task.amount / actor.competence \quad (2)$$

where a task's actual difficulty depends on the relevant project's complexity and its own difficulty level among all tasks, i.e.,

$$task.actualDifficulty=project.complexity*task.difficulty \quad (3)$$

The time unit used in the model is a simulation tick. As a result, the remaining amount of a task at every tick is given by:

$$task(tn+1).amount= task(tn).amount-actor.competence/task.actualDifficulty \quad (4)$$

Moreover, actors may make mistakes when processing tasks. The probability of making a mistake depends on the work quality of the actors; thus, the final mistake percentage of a task can be given by:

$$task.mistake=task.mistake+actor.mistake \quad (5)$$

#### 4.3.2.3 Submission

Submission occurs when an actor has a supervisor or a successor depending on the reporting structure and work process. In this case, the actor submits the task to the supervisor or successor when it has been finished, i.e., work amount becomes zero:

$$task.amount=0 \quad (6)$$

Then, the task is passed to the supervisor or successor, and the work amount is adjusted to its original value.

#### 4.3.2.4 Assigning

In some cases, managers may choose to assign tasks to their subordinates instead of conducting them themselves (such tasks are indexed with “assign=1” in task arrays). For

example, a project manager may assign look ahead scheduling to a project control specialist. When there are multiple subordinates, the managers need to choose one based on assigning preference (see Table 4.4). Then the task will be moved from the manager to the selected staff member, and the assign indicator of the task will be adjusted to 0.

#### *4.3.2.5 Requesting and approving job*

In a construction project, decisions are made at different levels. For some decisions, only project managers or president has the authority; while some decisions can be made by staff members. For example, in cost estimation, an estimator may have the right to determine the unit price of concrete framework based on means book or quota from suppliers. But the president might be the only person who can determine the final overhead rate. If approval from higher level of management is needed in order to process a project task, the actor has to submit the request. As a result, VOICE models the requesting and approving activities as particular behaviors in construction project teams. Each task has an authority level index indicating which level of actor has the right to process. If the authority level of a task is higher than the actor's level, the actor will check the approval status of the task to see whether it has been approved (approval status=1) or not (approval status=0). If the task has not been approved, the actor will submit it to the upper level actors for approval. For instance, the task "determining profit margin" might be a task beyond the senior estimator's authority; therefore he/she needs to submit this task to the president. Then the president will approve the profit margin and return it to the

requester. Asking for approval and approving are regarded as “management exceptions” in this model, which refers to the time spent on indirect work. Other management exceptions include: seeking additional information, returning unqualified work, reporting work stress-out, and etc. Such behaviors are not directly related to the work itself, and they have thus been considered to be an inefficient amount of time spent on a project. One of the aims of this model is to reduce such inefficient use of time.

#### *4.3.2.6 Conflict management*

Construction project involves the efforts of different disciplines. The cooperation between members from different organizations becomes a critical issue for most construction projects due to the possible misunderstanding of project goals and divergent interests (Baiden et al. 2006). When a conflict occurs between two actors, they may seek a solution directly between each other. For example, in proposal development, proposal team member requires intensive information from the engineering design team for quantity take-off. If a proposal team member cannot get necessary information for proposal development from the engineering team, he/she may contact the counterpart in the engineering team for additional information. However, if after several iterations the problem remains unsolved, the actor may seek help from his/her supervisor, such as a manager or a coordinator, for a better or faster solution. Then the supervisor may communicate with responsible actors or their supervisors. For example, a coordinator of the proposal team contacts a coordinator of the engineering team to expedite the



information exchanging between two teams. In certain cases, the supervisor might raise the issue to upper management such as president. Because of the involvement of higher authority, the conflict solving process may be expedited, but it adds up to nonproductive time. Whether to raise issues to higher levels depends on the preference of an actor, and the leadership style of the team leaders (such as micro-management preference).

#### *4.3.2.7 Information exchange*

Following Levitt's work (2007), construction project management activities can be regarded as exchanging project task related information. In some cases, there is a need for additional information for processing a project task. For example, in the proposal development of a power plant project, a proposal team member may need the job site configuration information from the engineers to make a preliminary estimation. Such information exchange channel is always different from the channel for work process. Take the same proposal development instance: although an information exchange happened between the proposal team member and an engineer, it is not necessary that there is a work relation between them. To reproduce such official/unofficial communications happening among actors, this model indexes the information status of every task. If  $\text{task.information}=1$  (instead of 0), it means additional information is needed. Then the actor will pass this task to the information source through the "information flow" structure. The information source then will index the  $\text{task.information}$  as 0 and return it to the requester.

During this process, a certain amount of time is spent based on the exception handling time of the actor, and the management exception indicator increases.

#### 4.3.2.8 Meeting

Meeting plays a critical role in construction project management (PMI 2008). VOICE models meeting as an event to reduce misunderstanding, enhance communication and solve problems pertaining to the construction project management. The president examines the management exception indicator at every tick, which shows the frequency of approval related activities, quality related activities, communication activities, etc.:

$$President.exception = \sum (approval\_related\_activities + work\_stress\_reports + communication\_activities + quality\_related\_activities) \quad (7)$$

If the management exception indicator is beyond the threshold of the president, the president will hold a meeting to solve the exceptions. The meeting duration is given by:

$$Meeting\ duration = a * (number\ of\ exceptions / threshold) \quad (8)$$

where  $a$  is the preference of the president. During the meeting, all actors (president, managers and staff) must stop their work. After the meeting, the management exception indicator will be cleared to 0; plus, all current tasks will be approved ( $task.approval=1$ ), the work quality will be improved (mistake percentage is reduced), and information will be shared thoroughly ( $task.information=0$ ).

#### 4.3.2.9 Monitoring

Some tasks pass through different actors. When an actor receives a task from others, he/she will check the quality of the work. In case the mistake percentage of the task is higher than his/her threshold, i.e.,

$$task.mistake \geq actor.mistakeThreshold \quad (9)$$

actors may adopt the following actions based on position and preference: correcting the mistakes themselves, returning the unqualified task to the responsible actors, or assigning this task to subordinates to correct. All actions require additional time and increase the management exceptions.

#### 4.3.2.10 Correction/rework

As discussed, if the quality of a task is not satisfactory, a series of reciprocal activities, i.e., “back-and-forward” actions will happen among actors. For all actors, if they receive returned tasks, they may need to make corrections or redo the entire tasks. In VOICE, returned tasks will be assigned highest priority, and the task mistakes portion will be treated as new tasks for processing.

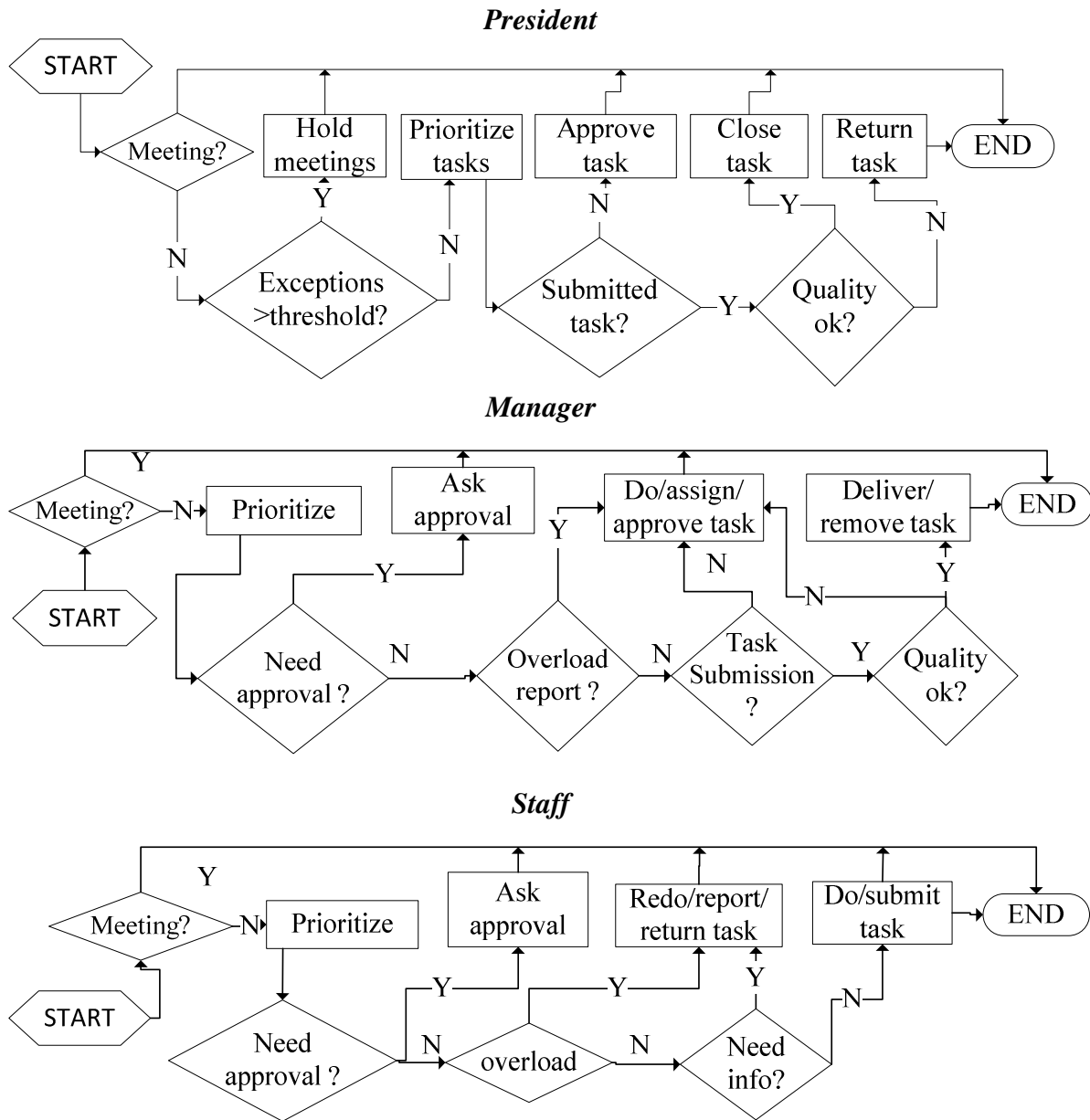
#### 4.3.2.11 Overburden

In this model, work related pressure is defined the as the total remaining work amount:

$$staff.workPressure = \sum (task.remainingAmount \times task.difficulty / staff.competence) \quad (10)$$

If the estimated work related stress is beyond the capacity of the staff, the staff will refuse additional tasks and report it to the manager for re-assigning. From the definition of reciprocal activities we can see that such activities are not relevant to the direct work, therefore, they are counted as management exceptions.

The above actions constitute the fundamentals of relational behaviors of between team members. For a particular case (i.e., different team members), the ultimate flowchart of an actor's relational behaviors is comprised of the above fundamental actions. For each of them, the upper half demonstrates the "action process," which refers to the actual work conducted by the actors, and the lower half demonstrates the "decision process," which means the decisions made on every contingency. In VOICE, although different actors possess different behaviors, the final behaviors and decision processes of a particular actor are a combination of these fundamental components. Figure 4.4 demonstrates examples of actors' behaviors, comprised of the above fundamental behaviors. For each flowchart, the upper half demonstrates the "action process" which refers to the actual work conducted by the actors, and the lower half demonstrates the "decision process" which means the decisions made at every contingency.



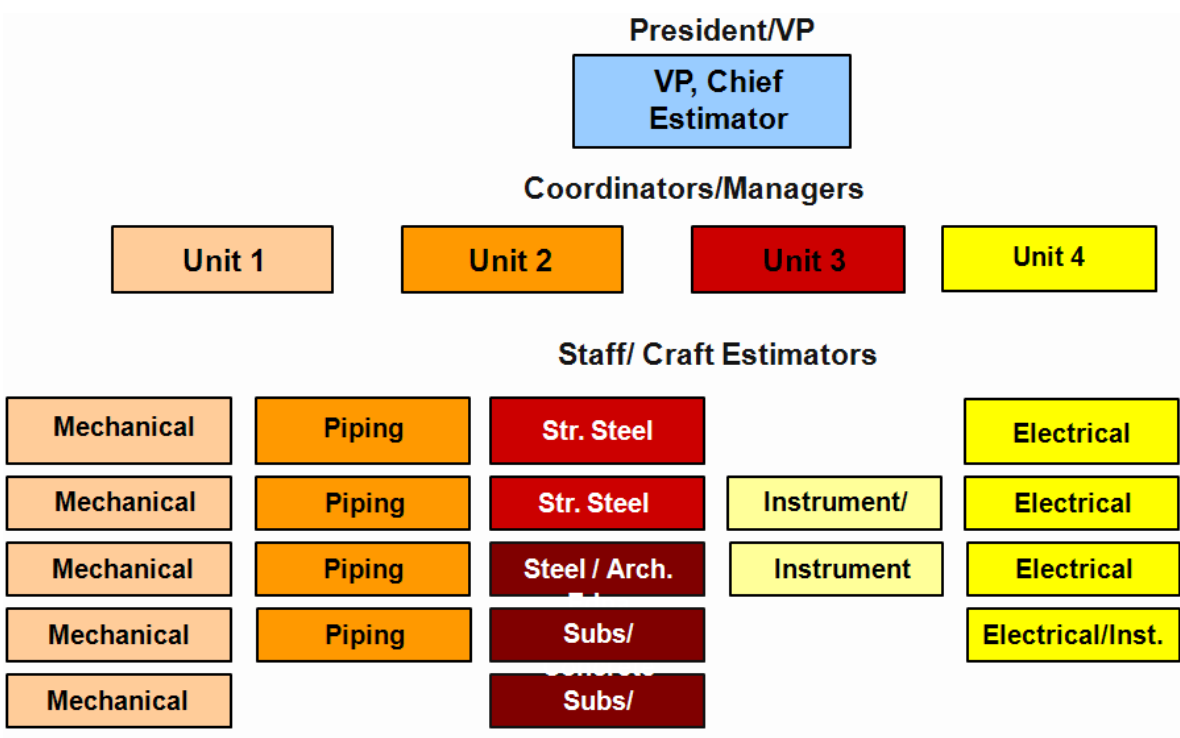
**Figure 4.4** Flowchart of actors' behaviors (example)

### 4.3.3. Modeling Organizational context

Following Chapter 3, VOICE represents a construction organization with three components: (1) reporting structure (or administration structure); (2) work process; and (3) information flow as the channel of information. Each component symbolizes a particular channel between actors when a related set of behaviors occurs.

4.3.3.1 Reporting structure

Reporting structure is the formal organizational structure that determines the arbitrary delegation pattern within an organization and reflects report directions. It can be demonstrated by a formal organizational chart (Daft 2009); therefore, official documentation was used to depict the organizational chart (Figure 4.5).



For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.

**Figure 4.5** An example organizational chart of a project proposal team

If there is no official organizational chart in a studied company, then a short interview was conducted with the president or managers to draw the organizational chart.

In VOICE, this administration structure is modeled as an association class connecting president, manager and staff. All authority relevant activities taking place among actors occur through the administration structure, such as “requesting and approving job” or “assigning job.” Figure 4.6 represents the administration structure by solid black lines, and the arrow represents the report direction. The current proposed model limits the administration structure to a three-level pattern. Additional levels will be presented in future work.

#### *4.3.3.2 Work process*

According to the literature, procedures within an organization are critical for the formulation of cooperativeness. The procedures are represented as work process in this research. Work process in the construction domain refers to the “necessary procedure in construction companies’ execution of their business” (Cheng and Tsai 2003) that typically includes the planning and control of projects through conceptual planning, design, bidding, construction, and commissioning (Shohet and Frydman 2003a). This research studies the work process as the pattern of task sequence and work arrangement, i.e., the channel that allows a sequence of managerial activities to flow through actors.

In VOICE, work process is modeled as an association class connecting actors and tasks. Direct task processing is executed via the work process structure. For example, an estimator (staff) is required to conduct a WBS analysis for a project. In VOICE, this task (WBS analysis) is passed from project to the estimator via the work process channel.

Once finished, he/she may pass the WBS analysis result to another estimator for further work. This is modeled in VOICE as passing the task from one actor to another via the work process channel.

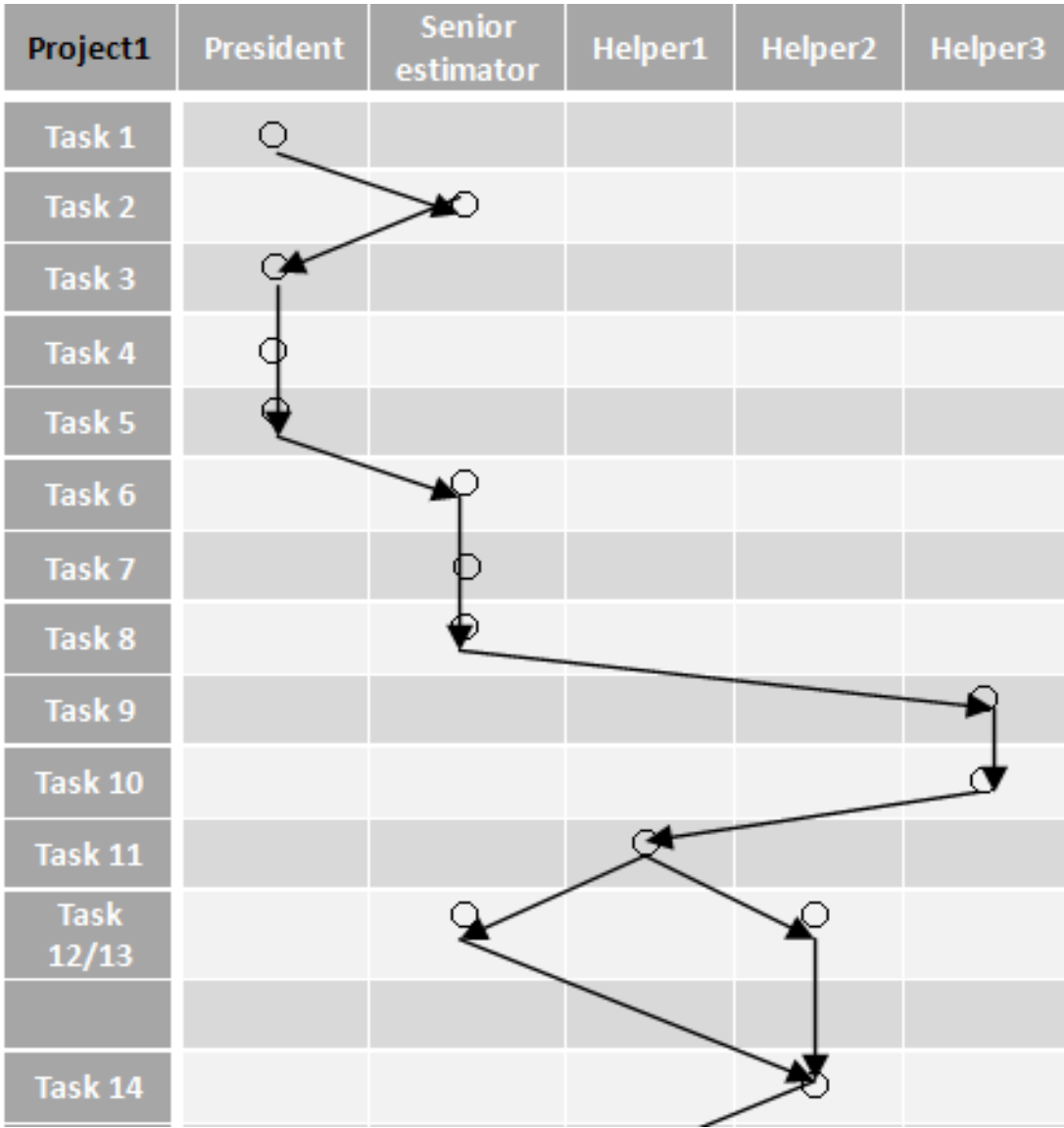
The work process is represented by developing a Task-Actor Relation Table (TART), which reflects the task assignment for every actor. First, the developed list of activities (Step 2, formulate representation of work) was sequenced based on the interviews. Process mapping technique was used as a communication enhancement tool. Then the follow-up semi-structured interviews and online-surveys were conducted to determine the responsibilities of each employee (Table 4.7). Finally, all information was collected to develop a TART table (Table 4.8). In this TART table, all the tasks (e.g., sub tasks of estimating) are arranged according to the sequence of the task queue (input by users), which is shown as the column heads; all the actors (e.g., senior estimator and his/her helpers) are arranged in the row head. Then, the cells are marked if an actor is responsible for a task (e.g., an estimator helper is responsible for quoting subcontractors). The work process pattern is shown with zigzag lines inside the TART (Table 4.8). Finally, the real world work process is translated to abstract task delivery pattern in VOICE (Figure 4.6).

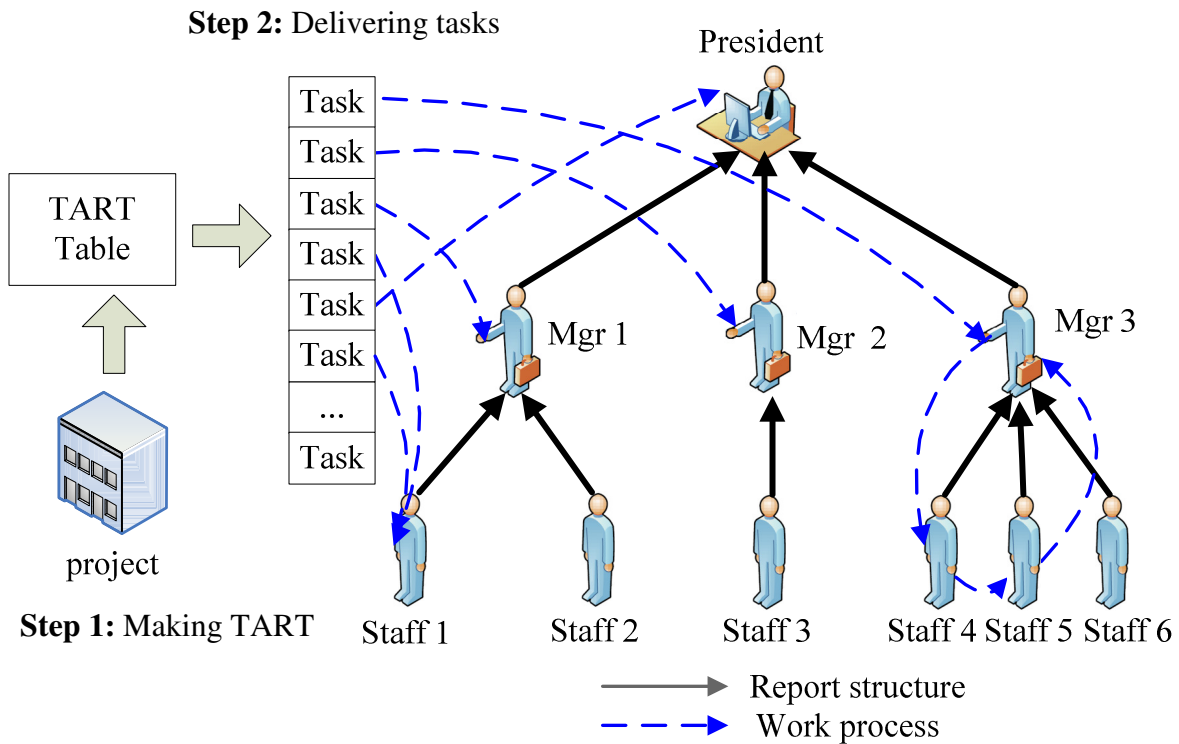
**Table 4.7** A sample survey showing individual responsibilities

Task Code	Name	Responsible employees		Signature
O.PLN.001	Study potential opportunities	A	S	
O.PLN.002	Contact subcontractors	A	S	
O.PLN.003	Price self performed work	A	S	
O.PLN.004	Evaluate subcontractors' quotes	A	S	



**Table 4.8** Task-Actor Relation Table (TART)





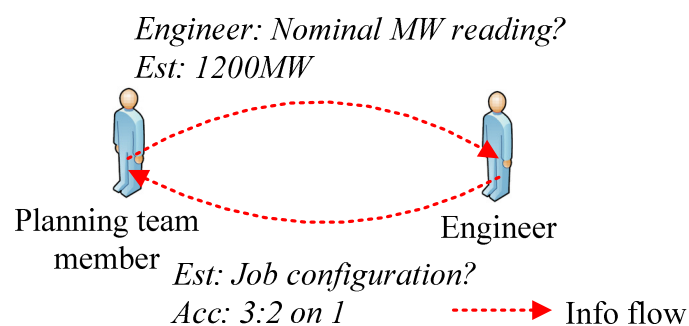
**Figure 4.6** Task delivery pattern in VOICE

#### 4.3.3.3 Information flow

Information flow is the formal/informal communication connection that determines the coordination, message and knowledge movement. Because information flow is the most intangible structure compared to the other two structures (reporting structure and work process), representing information flow requires intensive and reactive interview efforts except for document studies. Process mapping techniques were used to enhance the communication between the researcher and the respondents.

In VOICE, information flow is modeled as a set of channels where work related information is transferred from one actor to another, by modeling it as a class of

associations reflecting the coordination, message and knowledge movement among actors, while at the same time reducing uncertainty (Nonaka and Konno 1999). The movement of information is coded in the “ask-and-answer” fashion. For example, in a power plant project, an engineer needs critical information about the project specification from the project planning team member, such as the nominal Megawatt reading requirement from the client; this is modeled as passing the task with a null information status (task.infoStatus=0) from the engineer to the planning team member; and the planning team member’s answer can be modeled as changing the information status to applicable (task.infoStatus=1) and returning the task to the engineer. Meanwhile, the planning team member may need designing information for cost estimating, such as the job configuration. He/she then will send a task with a null information status to the engineer, and engineer’s answer can be modeled as switching the information status to applicable. As a result, the reciprocal information exchange activities can be demonstrated with two monodirectional flows (Figure 4.7).



**Figure 4.7** Information flow pattern in VOICE

#### 4.4. Output measurement

The framework of team performance proposed in Chapter 3 was supported by the domain experts from the studied cases. Accordingly, specific measures of the indicators, i.e., how the studied companies measure these indicators, are presented as follows:

##### 4.4.1. Time

The duration of a project ( $t_m$ ) follows functions 11 and 12:

$$project.size(t_{n+1}) = Project.size(t_n) - \sum task(t_n).amount \quad (11)$$

$$if\ project.size(t_m)=0, \text{ then } t_m \text{ is the time for a project} \quad (12)$$

Moreover, VOICE provides indicators for time used for different activities:

$$Total\ time = process\ time + communication\ time + idle\ time \quad (13)$$

$$Work\ time = process\ time + communication\ time \quad (14)$$

$$Effective\ time = process\ time \quad (15)$$

Idle time is the span of time when the actors “have nothing to do” (normally this is due to waiting), and process time stands for the time directly used for processing the tasks, following this equation:

$$\begin{aligned} Process\ time &= task.actualDifficulty * task.amount / actor.competence \\ &= (project.complexity * task.difficulty) * task.amount / actor.competence \end{aligned} \quad (16)$$

#### 4.4.2. Quality

Quality of a project team is associated with “detected failed production work volume” (Jin and Levitt 1996). This research uses a mistake percentage to represent the failed production work amount of each task, which ranges from 0 to 1 (100%). Provided that processing tasks are the sole function of a project team in this research, the ultimate quality of the entire teamwork is thus described as one minus weighted sum score of task mistakes, as shown in the following function:

$$project.quality = 1 - \sum (taski.amount * taski.mist) / project.size \quad (17)$$

where *taski.mist* stands for the percentage of mistakes in a particular task and follows this equation:

$$task.mist(after\ processing) = task.mist(before\ processing) + (1 - staff.quality) \quad (18)$$

#### 4.4.3. Effectiveness

Following Jin and Levitt’s (1996) work, the effectiveness of a project team is defined as the percentage of productive work time versus total work time. This research therefore formulates effectiveness as a ratio of effective work time (direct processing of tasks) to total work time. It is given by the following function:

$$project.effectiveness = \sum (effective\ time / Total\ time) \quad (19)$$

#### 4.4.4. Efficiency

Levitt (2007) defines two types of efficiency for any project team. Among them, time efficiency is given by a ratio of estimated work duration to simulation duration. If setting simulation duration to a standard unit of time such as one day, the estimated work duration demonstrates the actual work (measured in man hours) that can be finished by the team within one day. It reflects the average work amount completed per time unit. This research follows a similar definition and measures efficiency as:

$$project.efficiency = \sum task_i.amount / Total\ time \quad (20)$$

#### 4.4.5. Work related pressure

Work related pressure is a subjective judgment made by team members regarding the relation between work environment and individual ability (Cox et al. 2010). Although it is hard to quantify, perceived work related pressure is directly related to the workload (Hall 2004). From a purely technical perspective, this research measures work related pressure as total work amount (measured in time) of all tasks at hand:

$$staff.workPressure = \sum (task.remainingAmount \times task.diff / staff.comp) \quad (21)$$

$$task.remaingingAmount = task.amount - finished\ amount \quad (22)$$

#### 4.5. Basic assumptions of VOICE

The basic assumptions of VOICE have been addressed in previous sections. This section summarizes them in table 4.9 for the better reference of the readers:

**Table 4.9** Major assumptions of VOICE

	Agents	Assumptions
Input	Project	<ul style="list-style-type: none"> <li>• A project can be divided into a sequence of executable work efforts called tasks;</li> <li>• The project is completed once all its corresponding tasks are finished;</li> <li>• Multiple projects can be handled by a team simultaneously.</li> </ul>
	Task	<ul style="list-style-type: none"> <li>• A task is the most basic executable work effort for a project team member;</li> <li>• Task amount is measured by “hours”, i.e., how many hours it takes to finish a task by a team member with average competence;</li> <li>• A task is finished when task amount equals zero; Once finished, it will be removed and its amount is reduced from the project;</li> <li>• Tasks have different priorities; A task with higher level of priority is processed first;</li> <li>• Some tasks need approval from managers or president, or additional information before processing;</li> <li>• If a task is dependent on another one which has not been finished, it cannot be processed;</li> </ul>
Process	Individuals	<p>There are three major roles in a construction project team, including president, manager and staff member. The major responsibilities of them are:</p> <ul style="list-style-type: none"> <li>▪ President: holding meetings, handling exceptions, approving jobs and etc;</li> <li>▪ Manager: Assigning tasks, coordinating conflicts, quality monitoring, handling exceptions (e.g., team members’ complaints about overburden), approving jobs, attending meetings and etc;</li> <li>▪ Staff: Processing tasks, exchange task related information, delivering or submitting finished tasks, quality monitoring, reporting exceptions, attending meetings and etc.</li> </ul> <p>Specific assumptions are shown in 4.3.1</p>
	Relational behaviors	<p>VOICE models the following relational behaviors. Each behavior is modeled as a “behavioral module” in a “Library of Behaviors” (see appendix 3). In VOICE, an actor will first examine the situation. Then based on his/her judgment on the situation and his/her preference, a certain behavioral module will be triggered.</p> <ul style="list-style-type: none"> <li>• Prioritizing: An actor can only process one task at a time; therefore prior to further actions, an actor may order all tasks in hand based on the readings of their priorities;</li> <li>• Processing: Processing a task means reducing certain amount from the task every simulation tick. The amount reduced depends on task difficulty and competence of the actor. During this process, actors may commit mistakes shown as a mistake percentage of the task. The mistake of the entire project is measured by the weighted</li> </ul>

**Table 4.9** Cont'd

Agents	Assumptions
	<p>mistake percentage of all its tasks;</p> <ul style="list-style-type: none"> <li>• Submission: Once a task is finished and there is no successive actors (according to work process), the actor will submit the task to his/her superior;</li> <li>• Assigning: A manager may assign a task to his/her subordinates based on the assigning preference (e.g., speed driven or quality driven);</li> <li>• Requesting/approving: some tasks require approval from superiors; in this case, the actor will render this task to his/her superior, who will approve the task or render it again to his/her superior based on the technical information of the task and authority level of the actor. After a while (depending on the actor's exception handling time), the approved task will be returned to the requestor;</li> <li>• Conflict management: If a conflict cannot be solved by staff members, it will be raised to the manager or coordinator for further actions;</li> <li>• Information exchange: If the available information for a task is less than the required information (measured as a percentage), the actor will send this task to another actor (with needed information). After a while (depending on the actor's exception handling time), the task will be returned to the requestor with necessary information;</li> <li>• Meeting: If the number of all exceptions in a team is bigger than the threshold of the president, a meeting will be held. The duration of a meeting depends on the number of exceptions and preference of the president. After a meeting, all tasks are approved, information is provided, and exceptions are cleared;</li> <li>• Monitoring: If the mistake percentage of a task is bigger than the threshold of a staff member or a manager, it will be returned to the original actor, or will be corrected at a cost of additional time and etc. The reactions to unqualified tasks depend on the preference of the actor.</li> <li>• Correction/rework: If an actor receives a returned task marked as unqualified, he/she will redo it to improve quality. The time spent on correcting/redoing a task depends on the mistake percentage of the task and competence of the actor;</li> <li>• Overburden: An actor sums up total amount of tasks (burden) in hand – if this number is bigger than his/her capacity, he/she will suspend working, and return new tasks to the manager. The manager will reassign it to a staff member with smaller level of burden.</li> </ul>
Organizational context	<ul style="list-style-type: none"> <li>• Reporting structure: It is assumed that construction project team has a three level hierarchical organizational structure;</li> <li>• Work process: The procedure of processing a task; it shows the</li> </ul>

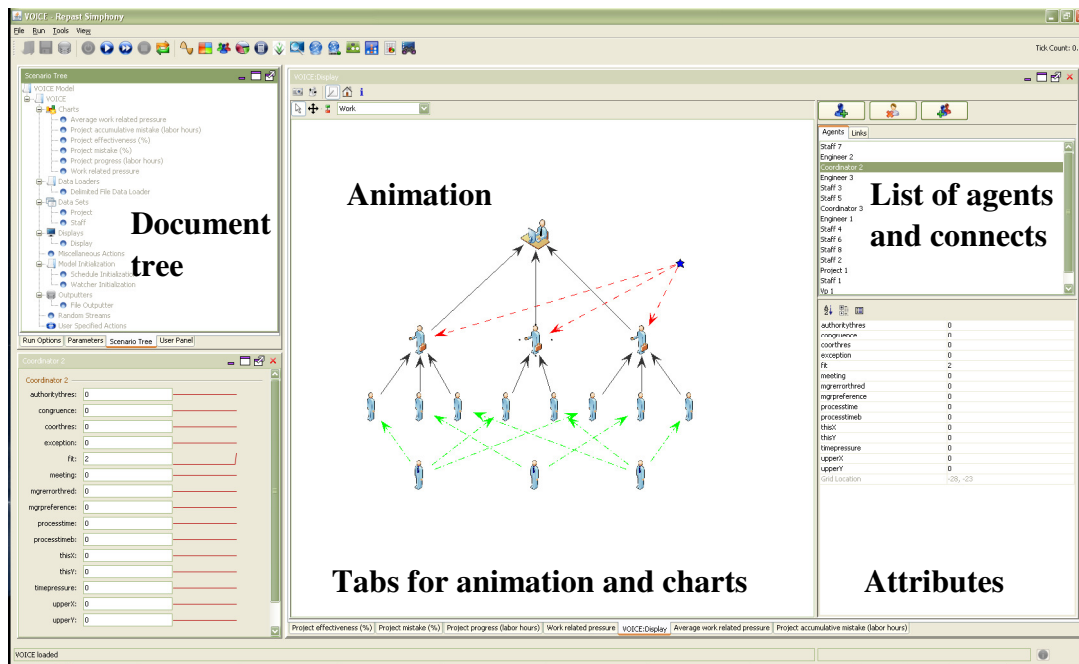


**Table 4.9** Cont'd

<b>Agents</b>		<b>Assumptions</b>
		sequence of delivering a task among team members. It always starts from a manager; <ul style="list-style-type: none"> <li>Information flow: The channel connects information requestors and providers. Information only refers to task related information, i.e., that is needed for processing a task. Two-way information flow is modeled as two one-way information flows.</li> </ul>
<b>Output</b>	Outcome performance	<ul style="list-style-type: none"> <li>Time: Hours spent on a project;</li> <li>Quality: The mistake percentage of a project, which equals weighted average of the mistake percentages of all its tasks.</li> </ul>
	Process performance	<ul style="list-style-type: none"> <li>Efficiency: Finished task amount per unit time (hour);</li> <li>Effectiveness: Ratio of productive time versus total time. Productive time is defined as time directly spent on processing tasks;</li> <li>Work pressure: Total work amount of tasks in hand for an actor;</li> </ul>

#### 4.6. Developing an integral platform

A set of ABM development platforms were compared in terms of their flexibility, richness of libraries, development user interface, analytical functions, and support from developers. REcursive Porous Agent Simulation Toolkit Symphony, or Repast S (Collier 2003) was determined to be a suitable development platform for this research. Repast S is a pure Java-based implementation, which has been widely accepted recently in academia. It builds on Object-Oriented Programming (OOP) where each object can be naturally regarded as an agent in VOICE. Repast S is an open source platform so the functions provided can be easily tailored to the requirements of this research. In addition, developers of Repast S have built an interactive supporting forum where development problems can be solved immediately. A snapshot of Repast is provided below (Figure 4.8).



**Figure 4.8** The runtime interface

#### 4.7. Summary

This chapter developed an Agent Based Model for interpersonal cooperation in the construction context named VOICE. VOICE builds on the conceptual framework proposed in chapter 3. In order to convert the conceptual framework to an executable simulation model, elements of interpersonal cooperation were conceptualized, and performance metrics were formulated. In the next chapter, a verification and validation framework for VOICE will be introduced.

## **CHAPTER 5: MODEL VERIFICATION AND VALIDATION**

Unlike a purely theoretical study, this research requires a certain degree of confidence in VOICE's ability to generate similar results as observed in real world construction teams, and in return, that decisions and analyses derived from it can be useful and convincing. Model verification and validation (V&V) are used to examine the extent to which VOICE acts in its designed purpose and generates results that are similar to observations.

### **5.1. Verification**

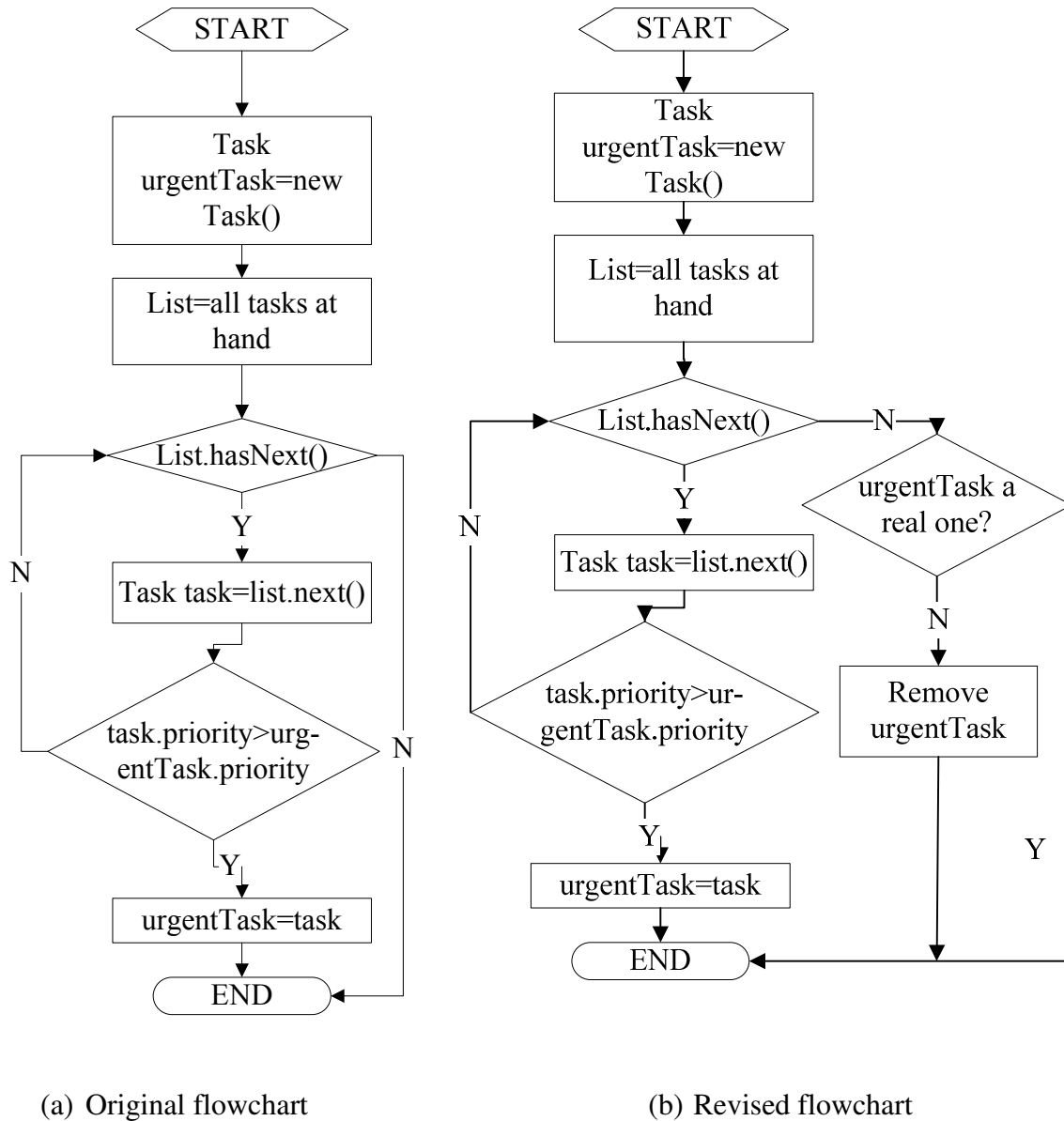
A verified model works as designed (North and Macal 2007). The following methods were used for verification, including code debugging, logic examination, unit test and hypothetical case test.

#### **5.1.1. Code debugging**

Java Eclipse (2012) provides an automated debugging framework and can help increase the efficiency of model programming by reducing the time spent seeking "failure-inducing circumstances." Early in the model development, all functional components of VOICE, including the model initializer, agent classes and implementation class were examined with the debugging function of Java Eclipse.

#### **5.1.2. Logic examination**

In order to verify the programming logic to be a correct realization of model design, the program flowchart of each model functional component was carefully examined.



**Figure 5.1** Logic errors detection by flowchart examination: example of prioritizing tasks

Figure 5.1 demonstrates a real example of a logic error detected in the programming of VOICE. In VOICE, all actors need to prioritize tasks prior to other actions. A dummy task is created at the very beginning with the least possible priority and named as urgentTask. Then a real task will be compared with urgentTask on their priority measures. The real task will be saved as urgentTask, replacing the dummy one if it has a higher priority.

Repeating this process, an urgentTask is finally obtained. However, a flowchart examination found a potential logic error in Figure 5.2 (a): when an actor has no real tasks at hand, the dummy urgentTask will be retained and processed further as a real one because actors cannot differentiate between dummy and real tasks. Therefore, a condition judge should be given to the selected urgentTask to determine if it is a real one. Using the same examination, flowcharts of all functional units of VOICE have been reviewed to make sure the model is programmed in the designed manner.

### 5.1.3. Unit test

The ultimate goal of model programming is to realize the designed function. Correspondingly, an examination should be performed to check if the program is coded “functionally.” There are two levels of “functionality”: (1) unit functional: each unit of the model works as designed; and (2) global functional: the entire model works as designed. To verify the unit functionality of VOICE, this research develops a method that involves the use of a test marker (an object with interested attributes) and corresponding check point. Table 5.1 lists thirteen functional units of VOICE, and their test markers and check points.

**Table 5.1** Test markers and check points of functional units of VOICE

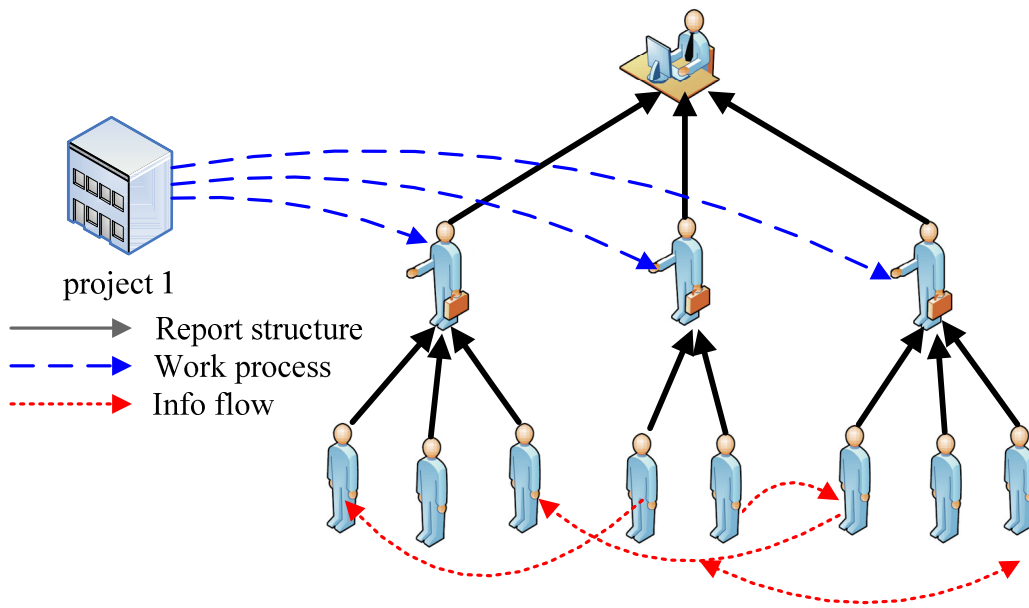
	<i>Functional unit</i>	<i>Test Marker(a dummy instance of agent for test)</i>	<i>Check point (when met, unit is functional)</i>
1	Prioritizing	A task that meets the following condition: testTask.priority=max(all tasks)	urgentTask=testTask
2	Processing	A task that meets the following condition:	testTask.amount(t+1)< testTask.amount(t)

**Table 5.1** Cont'd

	<i>Functional unit</i>	<i>Test Marker(a dummy instance of agent for test)</i>	<i>Check point (when met, unit is functional)</i>
		testTask.amount>0	
3	Submitting	A task that meets the following condition: testTask.submit=1	testTask.coordinates=upperLevel.coordinates
4	Assigning	A task that meets the following condition: testTask.assign=1	testTask.coordinates=staff.coordinates
5	Requesting	A task that meets the following condition: testTask.authority>threshold	testTask.coordinates=upperLevel.coordinates
6	Approving	A task that meets the following condition: testTask.approval=1	testTask.coordinates=lowerLevel.coordinates
7	Meeting	All agents meet the following condition: Agent.meeting>0	Agent.meeting(t+1)= Agent.meeting(t)-1
8	Monitoring	A task that meets the following condition: testTask.mistake>threshold	testTask.coordinates=submitter.coordinates
9	Correction rework	A task that meets the following condition: testTask.redo=1	testTask.mistake(t+1)< testTask.mistake(t)
10	Overburden	An staff that meets the following condition: staff. workburden>staff.capacity and a testTask	testTask.coordinates=upperLevel.coordinates
11	Requesting info	A task that meets the following condition: testTask.info<threshold	testTask.coordinates=infoSource.coordinates
12	Providing info	A task that meets the following condition: testTask.infofeed=1	testTask.info(t+1)> testTask.info(t) testTask.coordinates=requester.coordinates
13	Conflict mgt	A task that meets the following condition: testTask.iteration>threshold	testTask.coordinates=coordinator.coordinates

#### 5.1.4. Hypothetical case test

Two hypothetical cases were developed after consultation with domain experts to verify the global functionality of VOICE. The first hypothetical case explores if VOICE works with a one-project scenario. A single project is created, which generates a sequence of tasks as the inputs of an illustrative construction project team (Figure 5.2).



**Figure 5.2** An illustrative project team used in model verification

The values of attributes used in the simulation are shown in Table 5.2. To be noted, in order to simplify the hypothetical case, most attributes are assigned with deterministic values instead of random values.

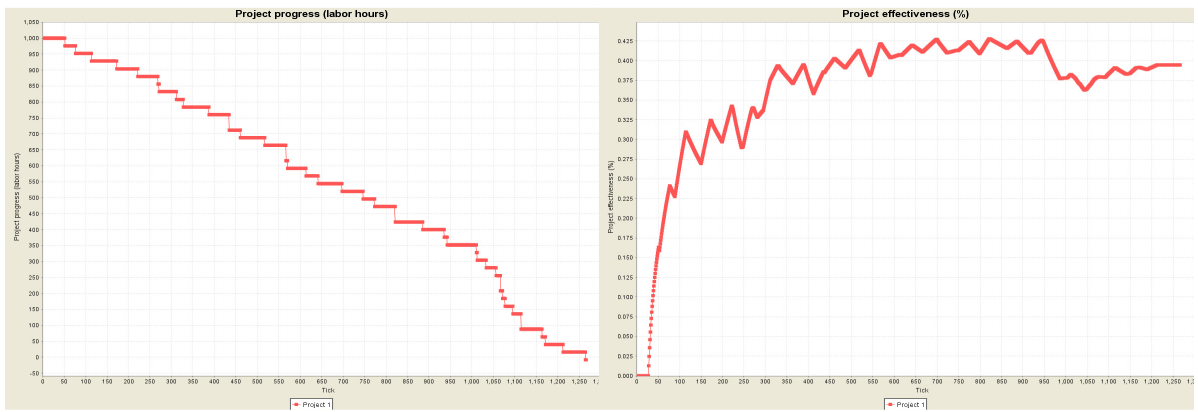
If VOICE is functional, the sequence of tasks will be processed by all relevant actors and team performance will be recorded and demonstrated at the end.

**Table 5.2** Values of attributes used in the hypothetical cases

	Attributes	Explanation	Value in simulation
1	Project size	Total work amount of the project	1000
2	Work amount	Work amount of every task	24
3	Difficulty	Difficulty of the project and every task	1
4	Priority	Priority of a task	Uniform (1,3)
5	Authority	Authority level of a task	Uniform (1,3)
6	Competence	Processing efficiency of an actors	1
7	Capacity	Most acceptable total work amount for an actor	20
8	Process time	Time needed for handling nonproductive exceptions	1
9	Mistake threshold	Threshold for a manager to accept a submitted task	0.1
10	Quality preference	1 means manager will returned unsatisfied tasks	1
11	Exception threshold	Threshold of the president to hold meetings	20

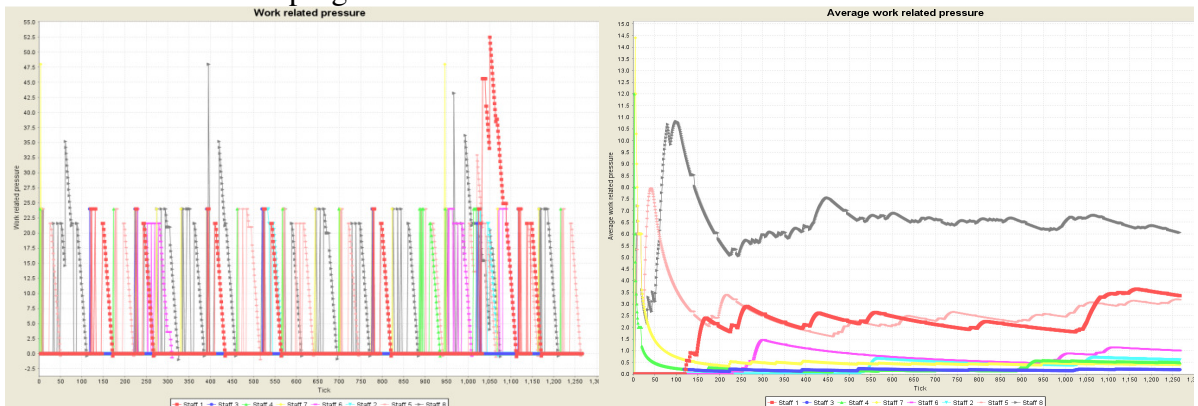
Figure 5.3 shows the performance outcomes of the first hypothetical simulation, including work progress, effectiveness, mistakes, work related pressure, etc. Similarly, the second hypothetical case was created to reflect a multi-project scenario. Three projects were created for the scenario, with each project size being 300. Values of other attributes remain the same as shown in Table 5.2. Simulation results show that VOICE is able to model the processing of three projects, differentiating the tasks of three projects and documenting the performance indicators individually (Figure 5.4). No warnings or errors were detected in either hypothetical case simulations. This supports VOICE's ability to work functionally in both one- and multi- project scenarios.





a. Work progress

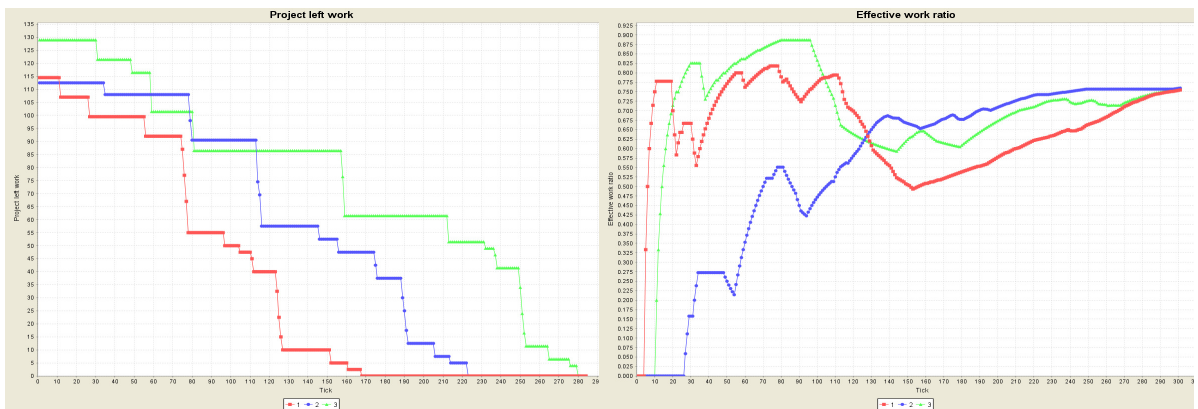
b. Effectiveness



c. Work related pressure

d. Average work related pressure

**Figure 5.3** Simulation results of the first hypothetical case (examples)

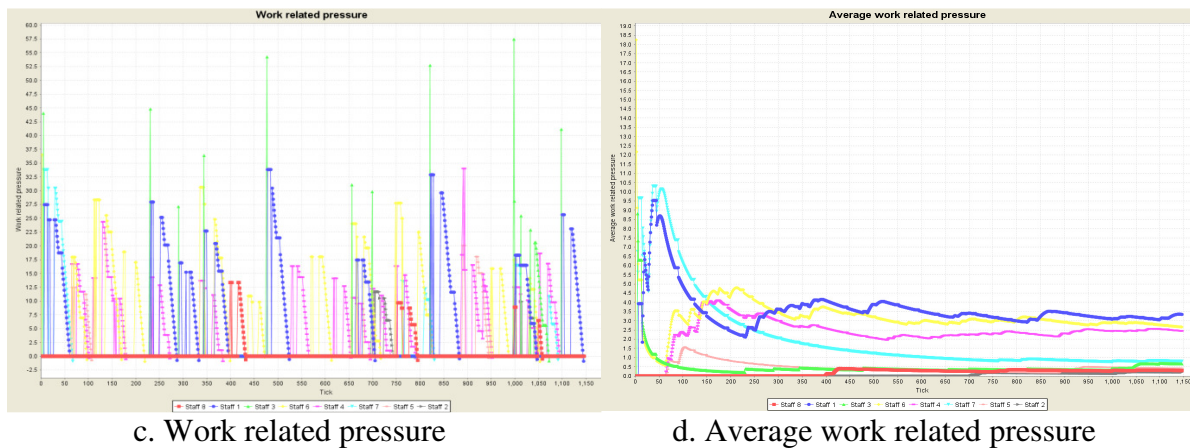


a. Work progress

b. Effectiveness

**Figure 5.4** Simulation results of the second hypothetical case (examples)

**Figure 5.4 Cont'd**



## 5.2. Validation

Literature has different definitions of validation. For example, Kleijnen (1995) claimed that validation is concerned with determining “whether the conceptual simulation model is an accurate representation of the system under study”. But Oberkampff et al. (2004) claimed that if a model can generate similar outputs as empirical data, it is validated. It is also worth noting that a perfect validation is unachievable (Rojas-Villafane 2010). The practical purpose of validation is to obtain sufficient confidence on the model in a hope that the simulation results can meet the needs of the research (Rojas-Villafane 2010). Because the main aim of this dissertation is to explain instead of to predict the influence of cooperation in construction settings, the target of validation in this research is to ensure VOICE to be able to reproduce the pattern of empirical data collected from case studies rather than exact predictions.

This dissertation has adopted a widely accepted validation framework proposed by Sargent (2004). Two steps were followed to validate VOICE: (1) input validation: data and conceptual model validity ensures the inputs of a model to be accurate and reasonable, and (2) output validation: output validity serves as a guarantee that the model will generate similar outputs as observed in reality.

### **5.2.1. Input validation**

Input validation aims to ensure that data and key assumptions used in VOICE can reflect the reality to a certain extent. In the beginning, multiple sources were used in order to triangulate the data collection. One source was surveys distributed to 34 domain experts with 515 combined years of experience who are believed to be the most relevant process owners in the studied cases. The second source was interviews of five key decision makers with 119 combined years in management positions, including vice president, principals, department heads, coordinators and managers. Third, when there were sufficient documents, such as time sheets, they were used to supplement the opinions. Then, descriptive statistical analysis was conducted, using the aggregated empirical data and model assumptions (especially behavioral assumptions) to reveal data patterns such as Probability Distribution Functions (PDFs). Last, the domain experts and/or key decision makers in case study companies commented on and validated the statistical findings, and the analysis was compared to document findings when applicable. This process started early in the model development and went through numerous iterations until enough confidence was obtained with regard to the validity of data and key model assumptions.

Additionally, when needed, onsite pilot studies were conducted to validate important model inputs, such as certain individual behaviors that are difficult to capture in surveys and interviews.

#### *5.2.1.1. Task information validation*

In VOICE, task duration is a random number drawn from a normal distribution. This was validated by findings from the document studies and surveys administered to process owners. On the one hand, most construction companies have well documented records that can be used as the basis of task duration validation. In one case study, the contractor provided seven-month time sheets, which specified the list of tasks with an internal coding system, task duration in hours, dates, phase in a project, and responsible actors (Table 5.3). These time sheets were organized by projects (using project codes provided by the contractor), where tasks of the same project were aggregated and analyzed. Initial statistical analysis found task duration follows a normal distribution.

In another case study, there were no similar time sheets. Therefore, instead of document study, this study relied on a series of surveys to 34 domain experts to collect task information. Figure 5.5 demonstrates two examples of survey results. Some respondents provided task duration in hours/days directly, while others gave an estimation of the percentage of each task for the entire work period. The latter ones can be easily converted to hours by timing the entire work hours. Similar to the previous case, initial statistical analysis was performed and normal distribution was found.

**Table 5.3** An example of time sheet

#	Task description	Duration	Date	Phase	Project
1	phone call; converse; email team	1	2.09.09	23-1040	CMI.9.5
2	phone call; converse; email team	1	2.10.09	23-1040	CMI.9.5
3	status of eviction, process	1	2.16.09	23-1040	CMI.9.5
4	phone calls; schedule; court bailiff	1	3.16.09	23-1040	CMI.9.5
5	phone calls; schedule; court bailiff	1	3.17.09	23-1040	CMI.9.5
6	phone calls; schedule; court bailiff	1	3.18.09	23-1040	CMI.9.5
7	phone calls; schedule; court bailiff	1	3.19.09	23-1040	CMI.9.5
8	phone calls; schedule; court bailiff	1	3.20.09	23-1040	CMI.9.5
9	36401 Tenant Eviction	2	4.14.09	23-1020	CMI.9.5
10	36402 Tenant Eviction	0.25	4.24.09	23-1020	CMI.9.5

Task Name	Task Description	Task Duration
Linear Scaffolding take-off		2 - 20 hrs
Material taking	Send take off to Materials	1 - 6 hrs
Quantities into P&O	Enter quantities into P&O	1 - 10 hrs
Comparison	Enter new project info into project comparisons	1 - 2 hrs
Enter quantities into P&O	Enter quantities into P&O	2 - 4 hrs
	into Hand	

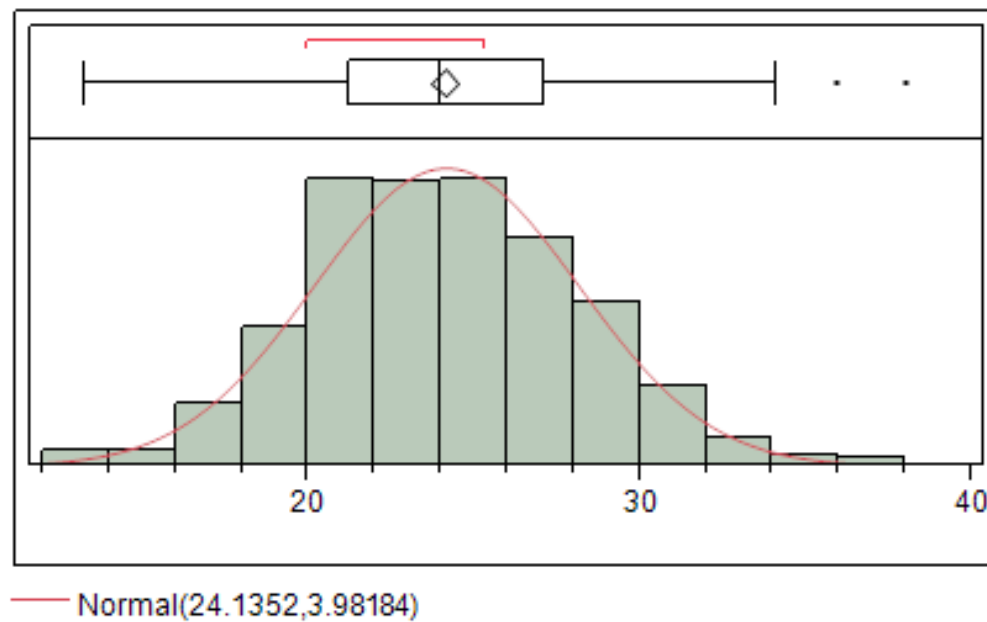
Task Name	Task Description	Task Duration
Know our experience	research of hist costs	5-10 %
Details of Scope	quantit. taken of 2nd characteristics	10-15 %
Measure Scope	key quantification	20-40 %
Extent of Scope	assumption basis	20-30 %
Consider Constructability	explore different ways & method	10-20 %
Design Alignment Mtg	align assumptions & design	5-10 %
Communicate	present at review &	10-15 %

The respondent fills the hours for each task directly

The respondent fills a percentage for each task

**Figure 5.5** Surveys to collect task information

In an aggregated analysis, it was found that the durations of tasks in these two case studies followed a normal distribution  $N(24, 4)$  with  $p\text{-value}=0.608$  (Figure 5.6). The mean value is 3 work days, which might be because respondents tend to report task durations in days or half days instead of hours. Thus, using a normal distribution in VOICE to generate tasks is validated.



**Figure 5.6** Distribution of task duration

Other task variables, such as task dependence and difficulty, are represented as a percentage or a range in VOICE. These variables were validated by the survey of 34 domain experts. For example, in order to validate the value of task dependence used in simulation, the domain experts were asked to describe their perceived magnitude of dependence, using a 5-point Likert scale. The results were further converted to a percentage to determine how many tasks could be processed when the preceding tasks were still underway. The results indicated this percentage follows a Poisson distribution.

This finding was validated by the domain experts. In the same way, all task information was validated with the confirmation from domain experts.

#### *5.2.1.2. Individual information validation*

Individual competence was mainly validated with an analysis of personnel documents. Due to the confidentiality of the assessment system, it was impossible to collect direct data of individual competence. Following the literature (Sandberg 2000; Humpel and Caputi 2001), the author proposed to quantify competence of employees by their years of experience. This method was supported by five key decision makers in case studies. In addition, years of experience for each position were collected, and a linear relationship was found between years of experience and their formal levels of skill. Therefore, the use of years of experience as an indicator of competence in VOICE has been validated. A survey was then conducted to solicit respondents' years of experience in current or similar positions. Results follow a two-peak normal distribution with mean value around 15.6 years. Thus in VOICE, actors with 15 years of experience possess a standard processing efficiency (competence=1) and competence values of other actors are proportional, based on their years of experience.

Other individual information, including exception handling time, work quality, quality threshold, exception threshold and preference were aggregated and converted to a range or as a distribution function. These ranges and distribution were validated during the interviews with five key decision makers since they have a better understanding of the

situation of the entire team. For example, aggregated data indicated that the quality threshold (acceptable mistake percentage) of managers follows a Pareto distribution. The decision makers supported this finding by asserting that only a small portion of managers tend to be extremely strict on work quality. Similarly, other individual variables used in VOICE were validated. In addition, several pilot studies were performed onsite by the author to validate certain individual information that is difficult to ascertain through surveys/interviews. An example was exception threshold of the president/VP. The author attended all emergent meetings in a case study company in seven months, and documented the discussion key points during the meetings as an indicator of the president/VP's threshold for emergent meetings. The author's observations were then compared to interview findings. The individual information used in VOICE reflects realistic situations.

#### *5.2.1.3. Organizational context validation*

VOICE assumes a three level hierarchical reporting structure. This has been validated by the formal organizational charts provided by the case study companies. The charts of both companies can be described as a classical functional organizational structure, with three levels: The top level is President/VP/Principals, whose responsibilities include scope management, proposal control, and communication. The middle level is managers/coordinators, who are responsible for work integration, quality control, coordination, and conflict management. The lowest level is staff, who are responsible for most specific tasks. This was also supported by findings of previous literature (Project



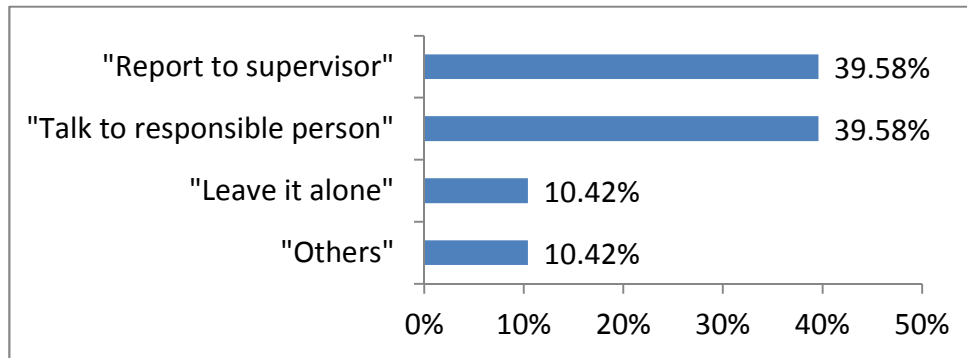
Management Institute 2008). For the other two aspects of organizational context in VOICE (work process and information flow), simulation models were compared against official documents for validation purposes. Specifically, job descriptions were studied to line up tasks with actors. Work flow documents were studied to examine formal information flow in teamwork. Because of the scope of VOICE, informal information flow was not considered.

#### *5.2.1.4. Behavioral assumption validation*

Behavioral assumption validation aims to validate the reasonableness of agent behavioral rules in VOICE. It includes two subtasks: (1) validating the list of behaviors, and (2) validating mathematical functions used in the simulation.

For the first subtask, the initial list of work-related behaviors was discussed with the five key decision makers in a series of face-to-face interviews. Their comments were considered to reflect more practical perspectives in the development of the list of behaviors. After several iterations, the list was finally confirmed by the key decision makers. Then, the 34 domain experts were asked to describe their major responsibilities and activities on a daily basis. Their answers were aggregated and classified to compare against the list of behaviors. A testimonial was finally made that the current list of behaviors used in VOICE (Table 4.6) reflects the most significant work-related behaviors and activities in both cases.

In order to validate the mathematical functions of behaviors used in VOICE simulations, a series of charts were prepared and validated by the five key decision makers. For example, empirical data found that team members' behavioral reactions to expectations (e.g., inferior information) can be grouped into four categories with different proportions:



**Figure 5.7** Behavioral reactions to exceptions

This chart was validated by the key decision makers in interviews: they claimed that based on their experience, most team members will seek help from the team or solve the problems proactively when needed. Only a small portion of team members adopt a passive action. Thus, the rules in VOICE concerning agent's reactions to exceptions were validated. By similar means, the important mathematical functions about other behavioral rules were validated.

### **5.2.2. Output validation**

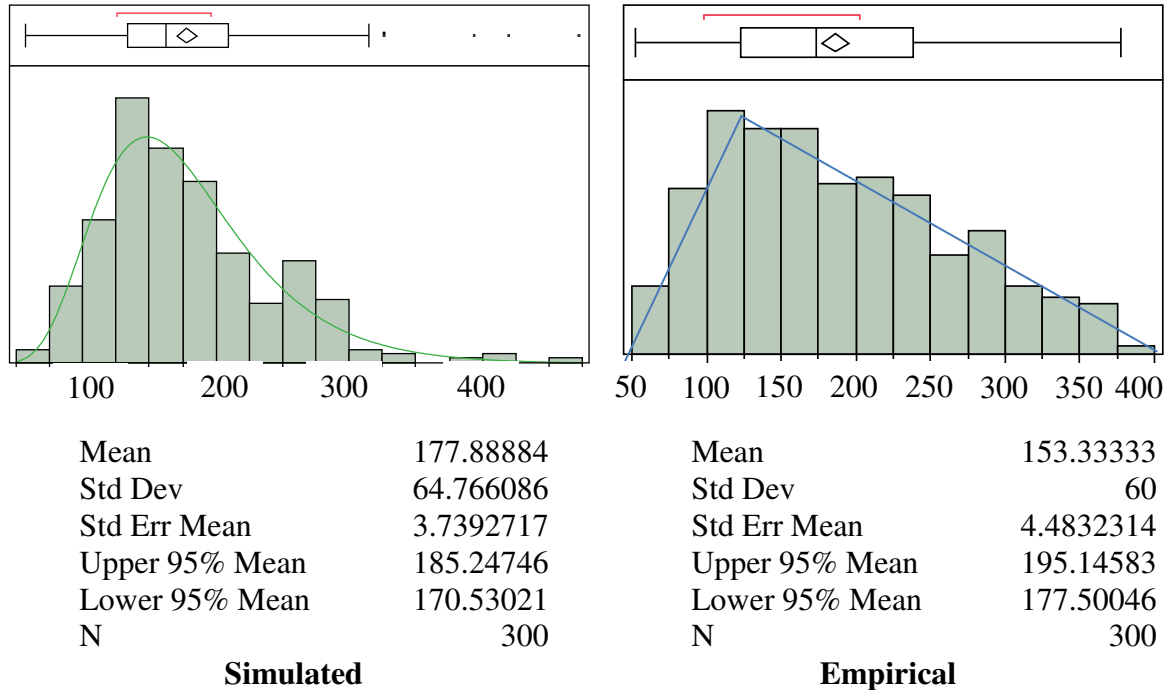
The purpose of output validation is to determine if VOICE is able to generate similar results to observations given rational inputs. In order to realize output validation, a well-structured scenario was modeled on VOICE to represent a representative proposal

development process by a project team of a studied company. Then the simulated results were compared against the empirical data collected from the same team.

In this representative scenario, project, measured as 500 standard man work hours, is processed by six staffs. The amount of each task follows the normal distribution found from observed data, and values of other attributes used in the simulation, such as staff competence, were randomly drawn from the PDFs validated in input validation phase. Then, simulation was repeated 300 times on VOICE, and results were summarized to fit probability distribution function for each performance indicator of VOICE. Then these simulated PDFs were compared visually against the PDFs of empirical data. If the PDFs are similar, it can be determined that VOICE works as observed. Statistical hypothesis testing was not used given the small sample size of empirical data.

Several key performance indicators were selected to validate VOICE's ability to generate similar outputs as empirical data, including work duration, quality, effectiveness, and the communication iterations between employees. The first indicator compared was work duration. The studied team didn't have record of durations of proposal development in the history. As a result, in the interview respondents were asked about their opinions about the work durations for proposal development. The reported minimum duration was one week (40 hours), while the maximum duration was 2 to 3 months (assuming 400 hours). The most likely duration, according to the respondents, is 2 or 3 weeks (assuming it is 120 hours). This ends up with a triangular distribution (40, 120, 400). Figure 5.8 (empirical)

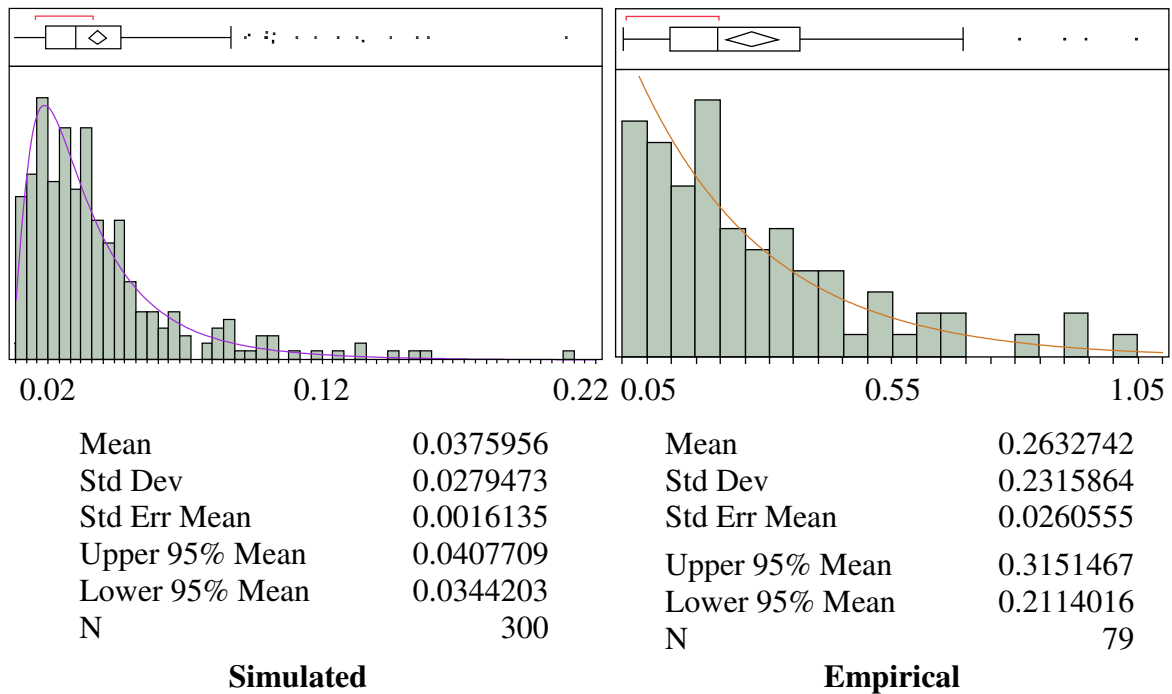
demonstrates the shape of this triangular distribution by generated 300 random numbers from the distribution. Then VOICE simulation was also repeated for 300 times, and a distribution function was fitted as figure 5.8 (simulated). Comparing simulated results against observed results, VOICE is able to generate a rational result of work duration.



**Figure 5.8** Distribution of work duration of the representative scenario

The second indicator compared was work quality, i.e., mistake percentage. The simulation was repeated 300 times in VOICE, and the mistake percentage values were collected to fit a distribution (figure 5.9, simulated). As shown, the simulated mistake percentage follows a lognormal distribution, with a heavy left tail. It means in most cases, the final mistake percentage of the proposal development is relatively at a lower level; bigger mistake percentage only happens in several extreme cases. However, it was very difficult to collect empirical data of mistake percentage to validate the simulated results directly,

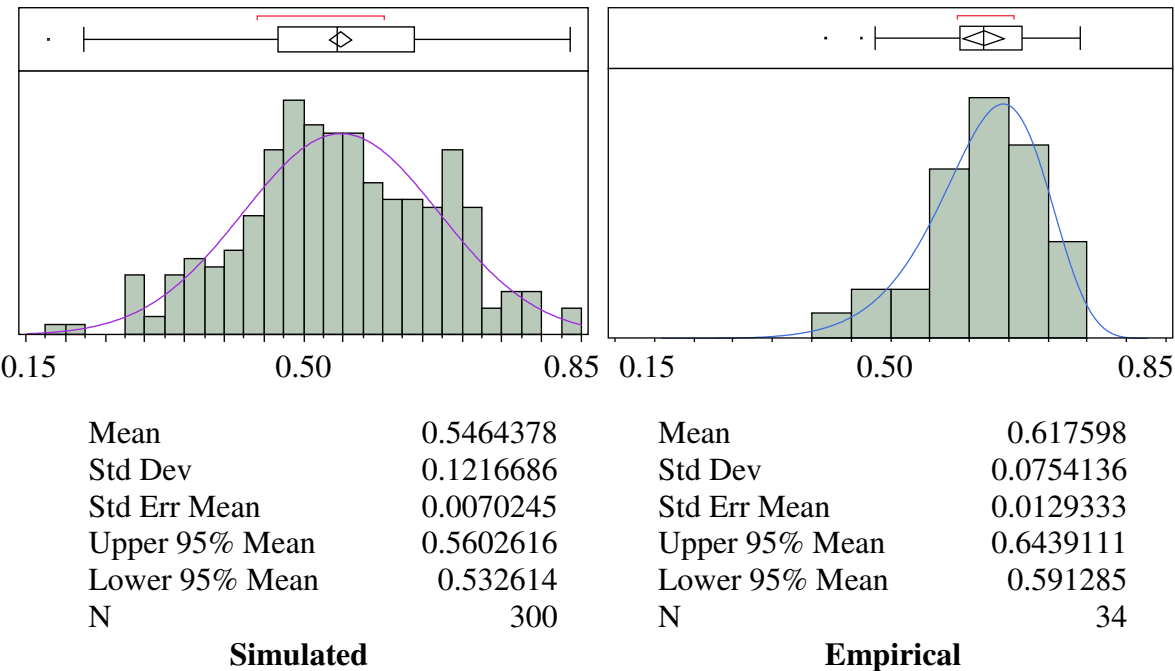
mainly because domain experts tended to have very different definitions for “mistake”, and in most cases, it was impossible to judge how much mistakes have been committed. Therefore, this research employed an indirect way to measure the quality of work. In case study companies, the author found that decision makers used an indicator called PF (performance factor) to evaluate the cost performance of the projects. PF is the ratio of actual cost versus budget. If actual cost is more than the developed budget, PF will be a number bigger than 1. On the other hand, PF will be smaller than 1 if actual cost is less than the developed budget. The absolute value of  $(PF-1)$  can also be used to estimate the goodness of proposal development: if the absolute difference between actual cost and budgeted cost of a project is bigger, it is always a signal that more mistakes are committed during the proposal development. This research collected PF values of 79 projects, and fitted a distribution to the absolute values of  $(PF-1)$ . Result indicates a Pareto distribution as shown in figure 5.9 (empirical). The shape of this Pareto distribution is very similar to the lognormal distribution fitted from simulated results, with both having a heavy left tail. It is therefore confirmed that VOICE is able to reflect the work quality of the simulated case, although not with a direct evidence.



**Figure 5.9** Distribution of mistake percentage of the representative scenario

The third indicator compared was effectiveness. In a survey, 34 respondents were asked to provide information of their nonproductive activities, i.e., activities not associated with direct processing of tasks, such as communication and waiting time. The author also conducted a work sampling for a month on a consecutive basis. Every day, 8 am through 5 pm, the number of people talking face-to-face or in a meeting was documented every 15 minutes. These results were integrated to obtain PDF of effectiveness in real project teams (figure 5.10 empirical). Then 300 simulations were conducted in VOICE to collect simulated effectiveness values. Results demonstrate a very similar distribution (figure 5.10 simulated) to the empirical data. The mean value of the simulated effectiveness is 0.55, which is slightly smaller than the observed value 0.62. Considering the errors in the

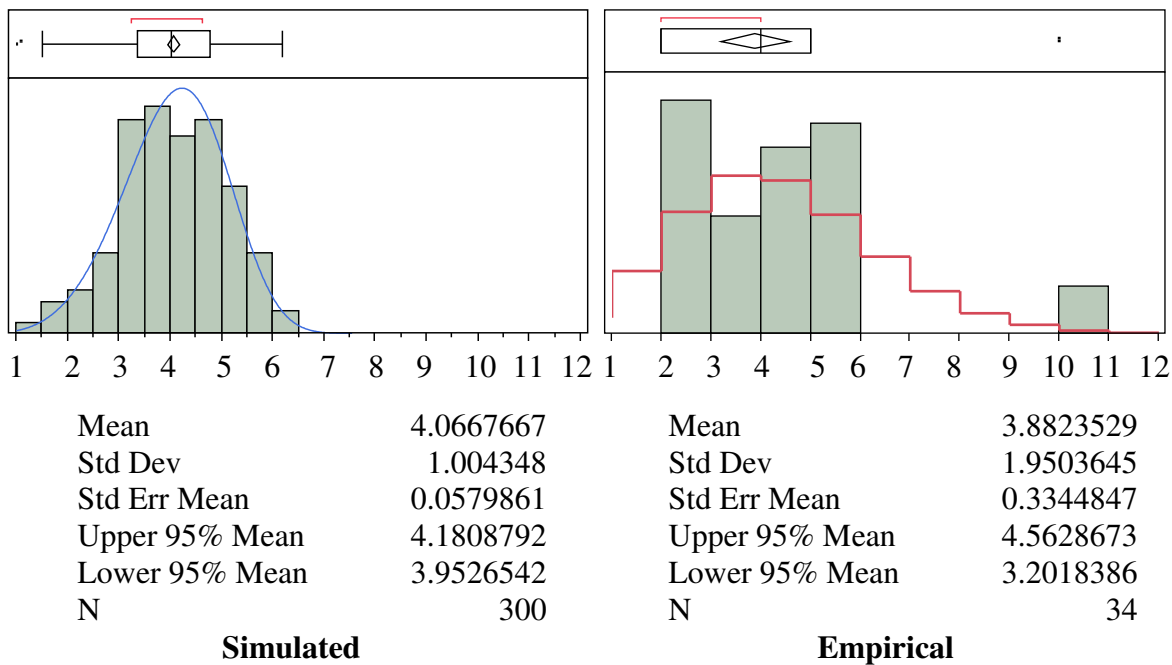
survey and work sampling, such difference is acceptable. It indicates that VOICE is able to reproduce work effectiveness.



**Figure 5.10** Distribution of effectiveness of the test scenario

The last experiment was aimed at validating VOICE’s ability to reproduce the key behaviors of the system. One important behavior is the number of communication iterations of between two team members to finish a task. For example, in order to develop a detailed quantity take-off, the estimator needs to obtain design information from the design team. But such information request can seldom be fulfilled in just one time. Indeed, many “back-and-forth” communications could occur during this process. In a survey, 34 respondents reported the most likely number of iterations in their work. These results were fitted against a Poisson distribution as shown in figure 5.11 (empirical). Simulation results (300 data points) were also obtained, and a distribution was fitted as shown in

figure 5.11 (simulated). Two distributions demonstrate similar shape, with mean values both around 4. This indicates VOICE is able to reproduce the key behaviors happened in the tested scenario.



**Figure 5.11** Distribution of number of iterations of the representative scenario

### 5.3. Summary

This chapter introduced the verification and validation framework for VOICE. The verification and validation aims to support VOICE’s ability to serve its designed purpose, and generate results that are similar enough to the observations. Certain validations were made indirectly as a result of an overall consideration of the validation quality and cost associated with the validation process (Rojas-Villafane 2010). Although only limited validation has been achieved by modeling a representative case of a studied company, certain level of confidence has been obtained that current VOICE can be used to conduct



exploratory simulations since it is able to generate similar results as observed for a representative case.

## CHAPTER 6: CASE STUDIES

This chapter uses two case studies to illustrate the capacity of VOICE to examine interpersonal cooperation issues in construction project teams. Each case study is organized in the following structure:

- **Case overview:** introducing the background of the case study and identifying the problems to be addressed;
- **Model assumption:** converting problems to the VOICE model and outlining the major modeling assumptions;
- **Model development:** tailoring the generic VOICE framework to specific problems, and formulating parameters used in simulation;
- **Simulation results:** presenting the simulation results
- **Interpretation of simulation results:** an overall summary and interpretation of the simulation results

### 6.1. Case Study 1: intra-team cooperation in estimating activities

This case study investigates how cooperative behaviors and the institutional arrangement between members of a single project team affect management actions and team performance in typical Design Bid Build (DBB) projects.

#### 6.1.1. Case overview

Company D is a small developer located in Michigan focusing on design and program development of residential projects. As a developer, this company bids for construction projects, such as new construction or maintenance. Most jobs are Design Bid Build (DBB)

and each of them needs an accurate estimation before bid submission. The cost estimation is conducted by a single team at company D: three managers work on separate sections/crafts of the project and all report to the principals for the final estimating and bidding decision. The following problems with D's cost estimation effort were identified during an interview with the principals:

- **Job acquiring capacity:** In company D, potential jobs are acquired by two principals. The estimation work is decomposed into a number of constituent requirements and assigned to the team. It is very difficult for the principals to “estimate” the proper workload for the team, i.e., how many jobs can be acquired simultaneously. There is a realistic need to investigate the maximum capacity of their team to work on estimation without overloading their employees.
- **Improper workload balancing:** experience has shown that unbalanced workload among team members may produce anxiety, inefficiency and unexpected lack of productivity.
- **Meeting frequency:** company D has a very flexible meeting policy. The principals tend to hold more meetings; however, this might bring new inefficiencies to the company. Complaints had begun to appear that too many meetings are purely wastes of time.

These issues were investigated with VOICE. Because company D had very concrete needs and data of specific projects, what-if scenario simulations were performed.

### **6.1.2. Model assumptions**

In order to utilize the VOICE framework to investigate problems discussed above, the following basic assumptions were made:

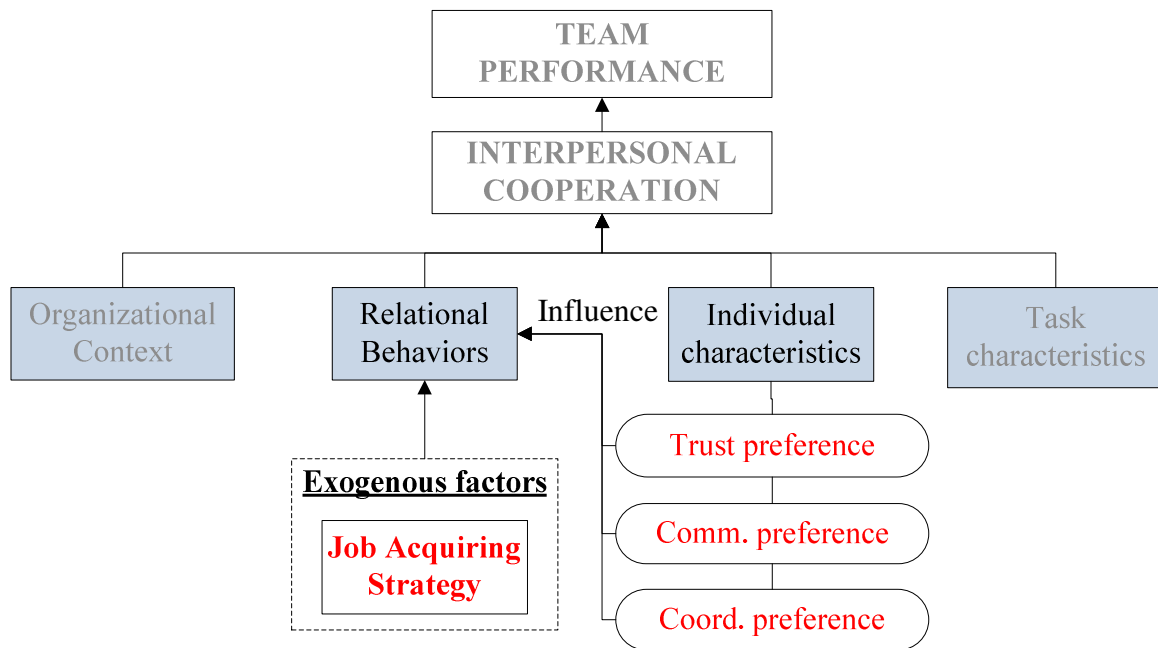
First, the job acquiring decisions of the principals may trigger a variety of individual behavioral responses modeled with the relational behaviors of the proposed VOICE framework. Typical behaviors include routine activities (e.g., processing tasks), communication, and coordination (e.g., assigning tasks). However, when overloaded, reciprocal activities may also be triggered, such as complaining about the overload. These nonproductive activities create inefficiency and affect the capacity of the estimating team.

Second, it was assumed that an unbalanced workload among team members was primarily attributed to the manager's task assignment preference. Therefore, to investigate the workload balancing issue, an investigation is needed to reveal the role of managers' task assignment preferences.

Third, in the estimating process, principals initiate meetings when too many technical errors and exceptions are perceived. Meetings bring direct changes to the team by influencing the magnitude of team members' behavioral responses. These interactions ultimately determine the quality of interpersonal cooperation in the estimating team and then, the performance of estimation.

Last, although under the VOICE framework, task characteristics and organizational context can also affect the cooperative behaviors of team members, they will not be

considered in this case study because they are less dynamic in Company D, compared to the four issues addressed by the principals. Therefore, the simulation experiments only focused on the controllable variables for a realistic recommendation.



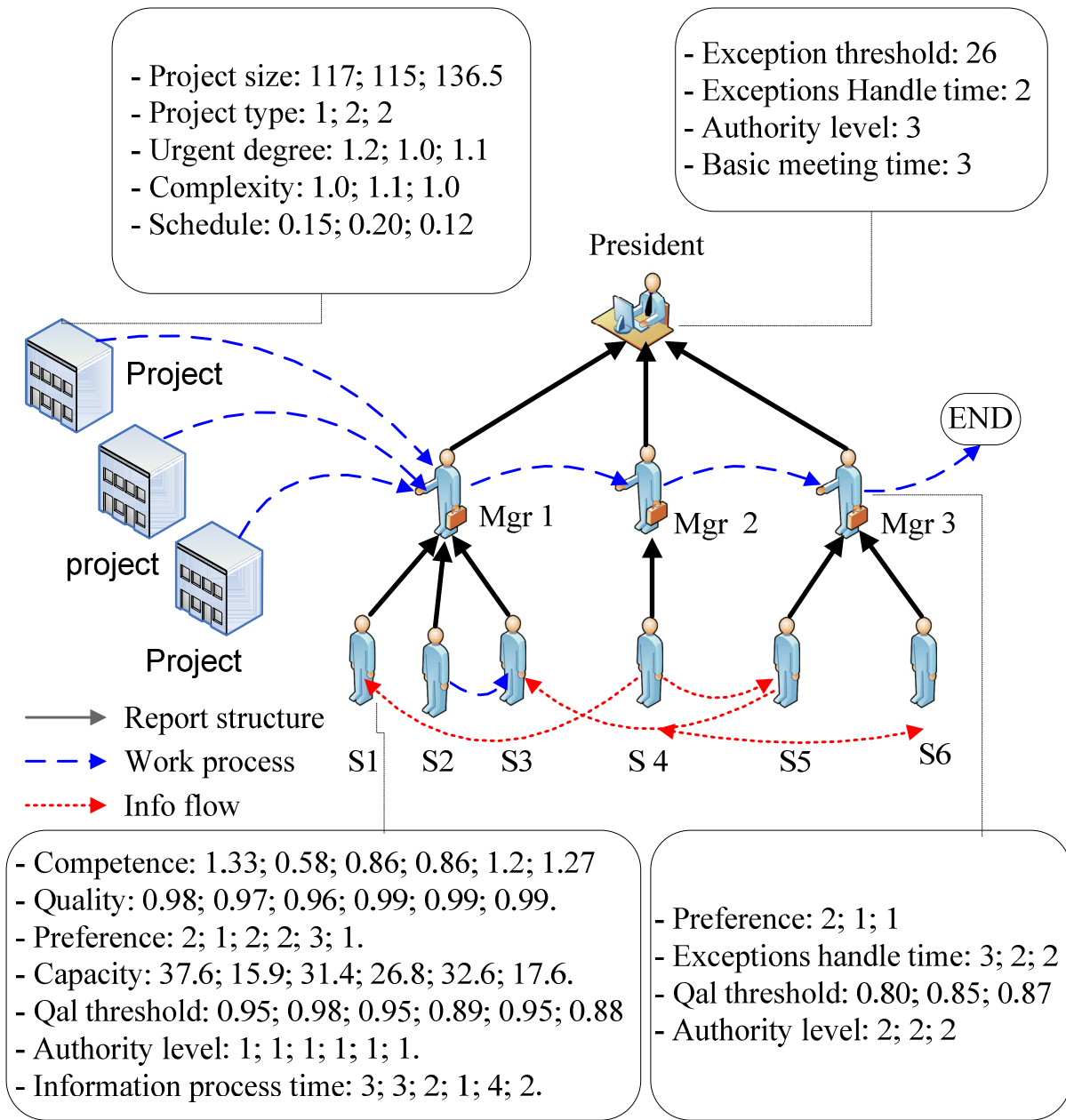
### 6.1.3. Model development

simulation experiments was collected and the simulation model was built as Figure 6.2. The case study model includes three simultaneous bidding projects: a set of tasks is generated by each project. For example, task 1 is “principal studies potential opportunity,” task 2 is “project planning manager contacts subcontractors,” etc. Based on predefined TART tables and user defined attributes, task attributes are embedded in the model, shown as arrays. For example, for project 1, the array for the tasks’ work amount is [5,5,10,15,15,10,20,20,25,10,5,5,10,15,20,15,10,10,5,5].

#### *6.1.3.2. Process*

Company D has a typical three-level organizational or report structure: Two principals acting as the head of the company are responsible for scope management, new job acquisition, negotiation and general management of the company. Note that, since the job responsibilities and decision making processes of these two principals are similar, they are considered as one role, i.e., president, in the company. Then, there are three full-time managers with the assistance of several full-time/part-time helpers.

The individual work related behaviors and decision processes were also embedded in the simulation model. Specific inputs are shown in Figure 6.2. In the following section, two examples are given to demonstrate how VOICE helps with the investigation of the influence of cooperative behaviors on team effectiveness. More details about the model for case study 1 are provided in Appendix 1.



**Figure 6.2** Snapshot of the simulation (case study 1)

#### 6.1.3.3. Outputs

According to the needs of the four issues, the performance indicators monitored in the simulation experiments include time (duration of estimation), quality (mistakes in estimates), effectiveness and work related pressure.

#### **6.1.4. Simulation results**

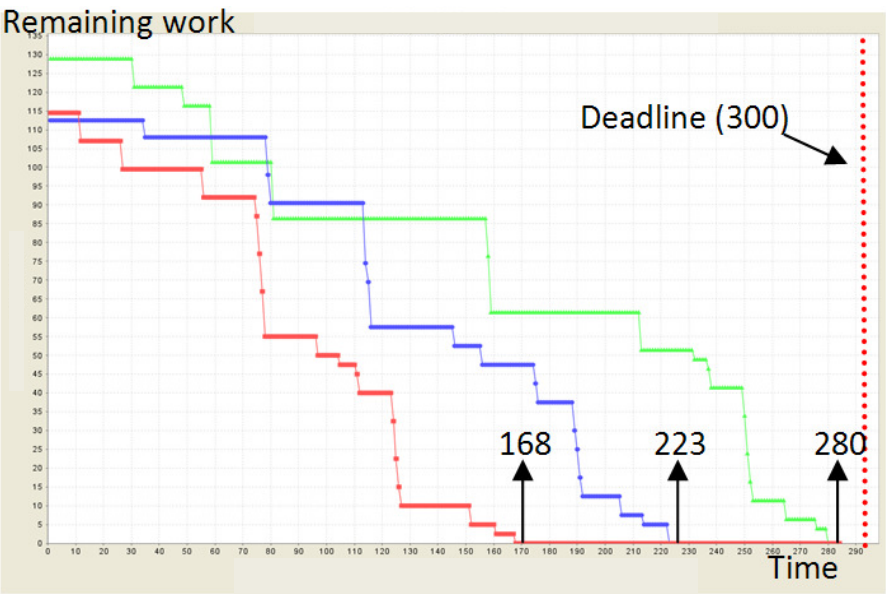
##### *6.1.4.1. Experiment 1: Influence of job acquiring decision*

In the past, the estimating team had been able to work on three projects concurrently. To test the maximum capacity, three-project and four-project scenarios were compared to analyze the influence of extra work. The extra project (project 4) is assumed to have the same parameters and processes as project 3, and all human factors, such as work efficiency, stay the same under the two scenarios. Figure 6.3 shows the simulation results, where the Y axis refers to the remaining work, and the X axis is the elapsed time measured in hours, whereby one tick equals one man-hour of work in reality. Therefore, the project's bidding work progress is demonstrated.

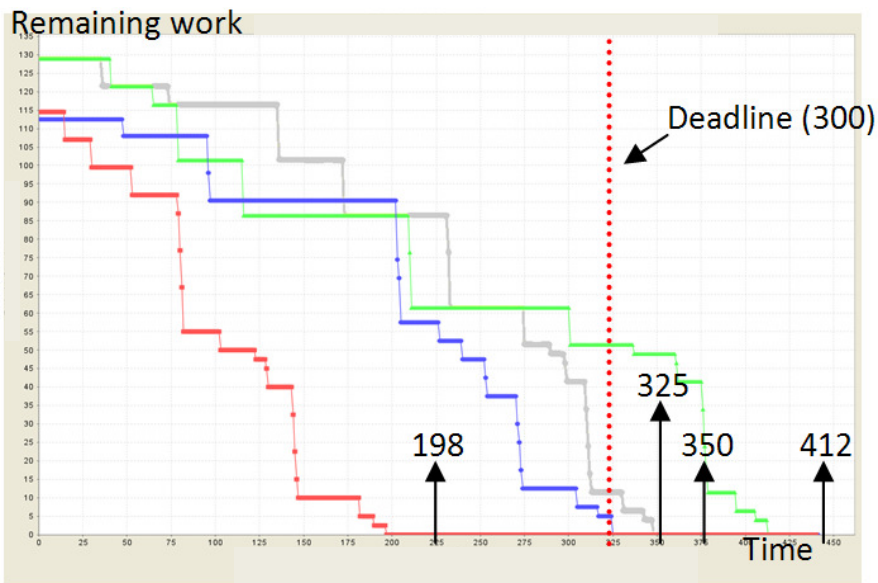
The results indicate that when bidding three projects simultaneously, all bidding work can be finished before the preset deadline (Figure 6.3). However, when bidding for four projects, three of them cannot meet the deadline, even though only one project is added to the work list. More importantly, the increase in work time is not a linear relationship with the number of projects: the total work hour spent on three projects is 671; it becomes 1285 when another project is added which is almost twice of the original number. The relationship between increased job load and estimated time for processing them can hardly be discovered by experiment because of the interferences among projects. Capturing the quantitative relationship is very helpful to answer a variety of practical questions like: *“how many additional projects can a construction team work on if it hires*



3 new staff members?” Such questions can hardly be answered by even the most experienced practitioners. VOICE thus could be used as a supporting tool for job acquiring decision makings.



(1) Bidding for 3 projects simultaneously

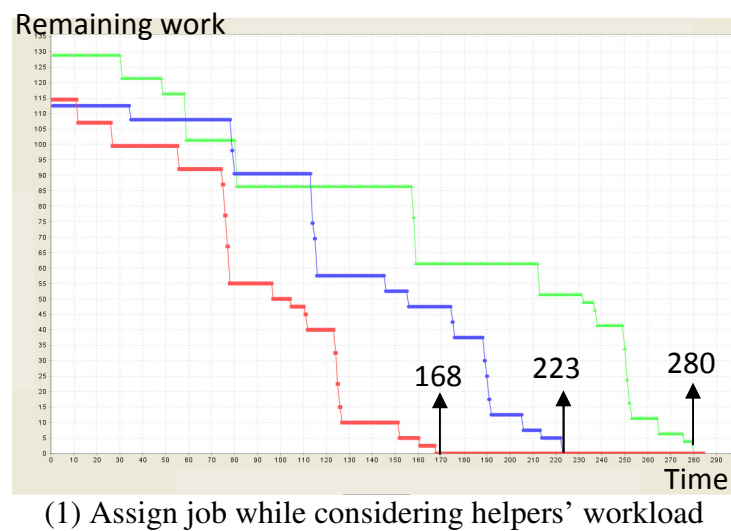


(2) Bidding for 4 projects simultaneously

**Figure 6.3** Real time bidding work progress (scenario 1)

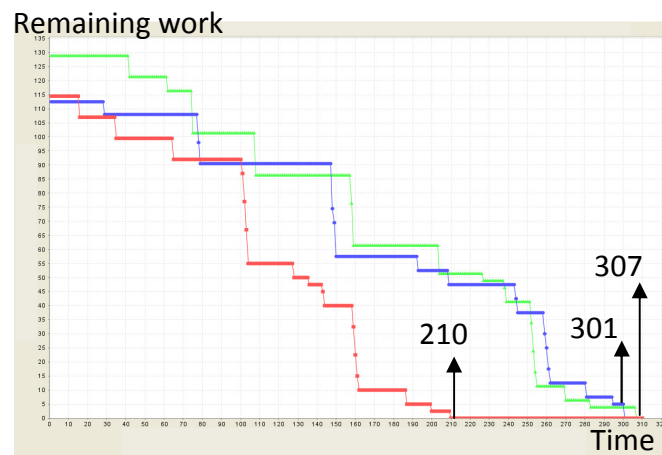
#### 6.1.4.2. Experiment 2: Influence of task assignment preference

An unbalanced workload among team members had been attributed to managers' task assignment preferences. Therefore, two major preferences were investigated in a what-if scenario simulation: (1) assigning tasks to staff with the least workload, and (2) assigning tasks to the faster staff. It was found that assigning jobs to faster staff does not always lead to faster completion. Figure 6.4 demonstrates that consistently assigning jobs to faster staff increased total work time for all projects. Figure 6.5 shows the work related pressure of staff. Under preference 1 (considering the workload), the biggest stress indicator is 17.6 for Helper 4; but under preference 2 (always assign jobs to faster helpers), this indicator is 21. According to the literature, greater work related stress reduces work efficiency, and helpers may refuse to work under some conditions, which means the manager must spend extra time to reassign the job. Managers' coordination behaviors affect work performance by affecting employees' work-related pressure.

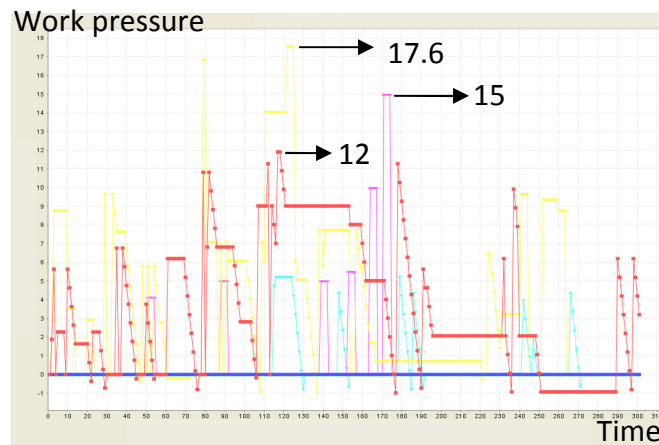


**Figure 6.4** Real time bidding work progress (scenario 2)

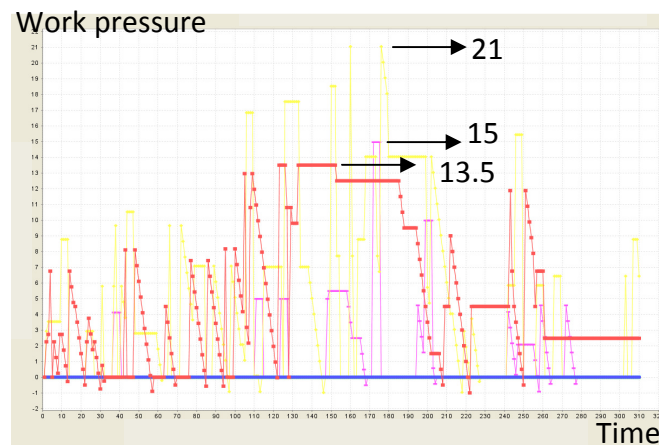
**Figure 6.4 Cont'd**



(2) Always assign job to faster helpers



(1) Assign job while considering helpers' workload



(2) Always assign job to faster helpers

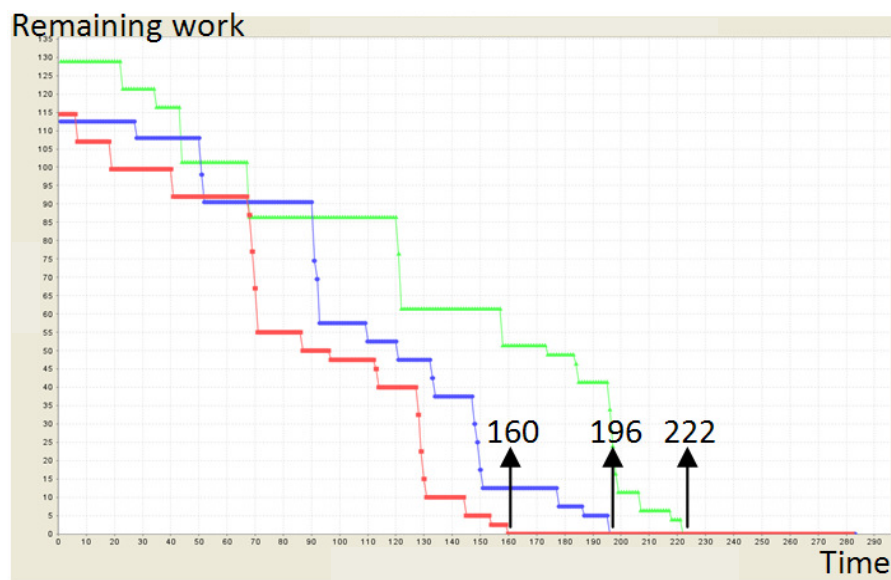
**Figure 6.5 Work related stress of helpers (scenario 2)**

#### ***6.1.4.3. Experiment 3: Influence of meeting***

In Company D, principals have the right to hold emergent meetings when they perceive too many management exceptions. These exceptions include but are not limited to: approval requests from helpers and managers, reports on job burnout, lack of necessary information, or conflicts between different departments. When the management exceptions exceed the principals' threshold, the principals initiate emergent meetings. During the meetings, all employees must pause their work for a given time, although (depending on how many problems must be solved), after the meetings, the problems are solved. For example, an assistant estimator will find it much easier to obtain worker payment information from the accounting department during the meeting; or the principals will announce the rules of determining profitability during the meeting so that employees do not need to ask for such information repeatedly. The principals want to know, however, the impacts of the frequency of emergent meetings.

Two strategies were considered: (1) more emergent meetings: the threshold of principals was set to 5, which means they are more sensitive to management exceptions; (2) fewer emergent meetings: the threshold was set to 50, which means principals are more tolerant of exceptions. More meetings does not necessarily lead to longer total work time: even though holding emergent meetings may be perceived as “wasting” time, the simulation results show that strategy 1 (more emergent meetings) reduces the total work time of all three projects (Figure 6.6). The reason is more emergent meetings benefited the company

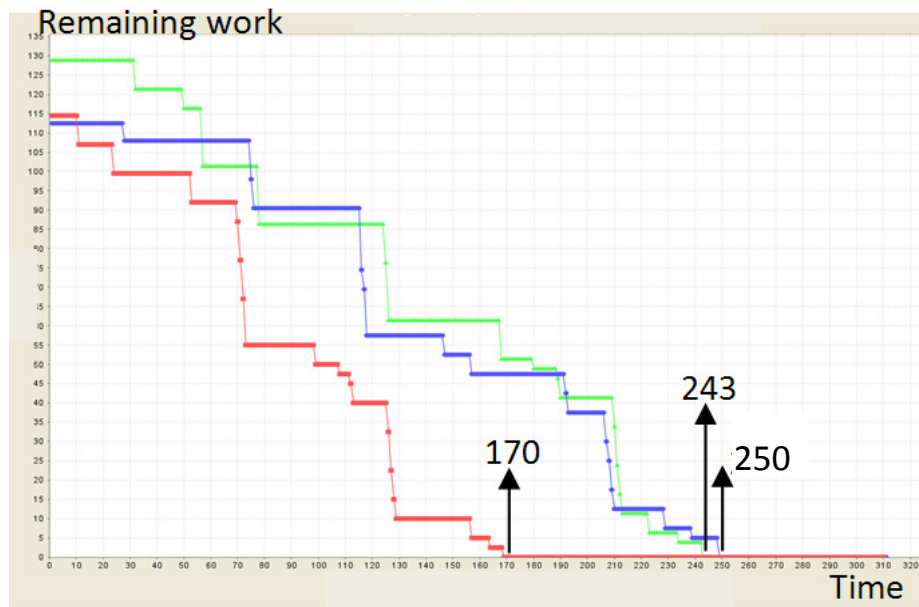
by increasing the accumulative work effectiveness (measured as a ratio of effective work time versus ineffective work time, where total time is the sum of effective work time, ineffective work time and idle time). Additionally, the effectiveness indicators under strategy 1 are more stable than under strategy 2 (Figure 6.7). This means that holding more emergent meetings does not affect employees' work; rather, it improves efficiency. Therefore, we advise the principals of company D to be stricter about management exceptions, and hold emergent meetings as needed. A further examination found there is a trade-off between time spent on meetings and additional efficiency gained from them. Figuring out a better frequency of meetings is a difficult task for decision makers because of the complex interactions of human behaviors, task characteristics and work processes. VOICE could be used for this purpose because in its simulation these interactions have already been captured as part of the emergent process.



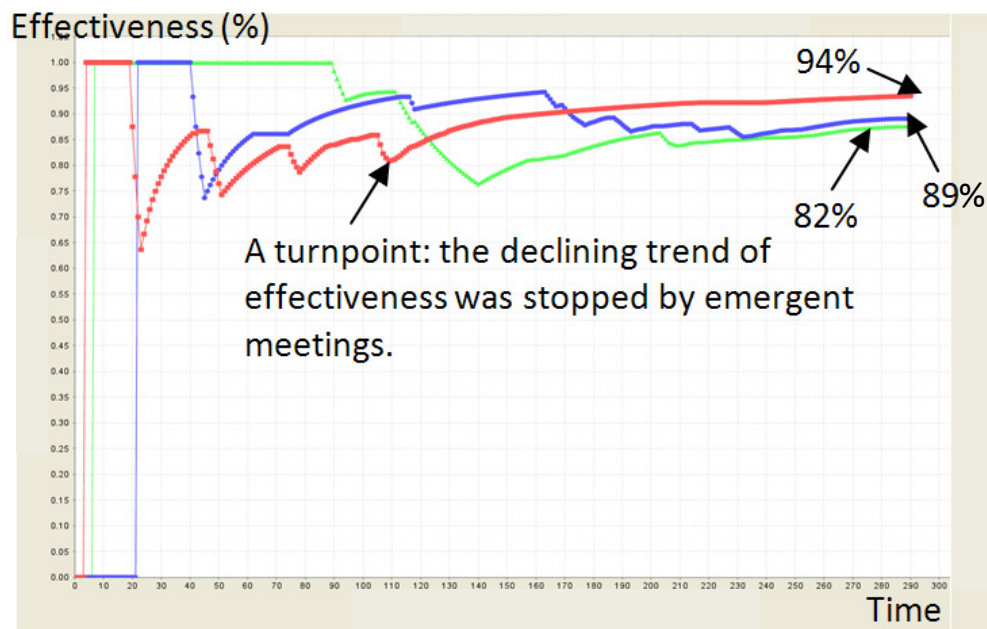
(1) More meetings

**Figure 6.6** Real time bidding work progress (scenario 3)

**Figure 6.6** Cont'd



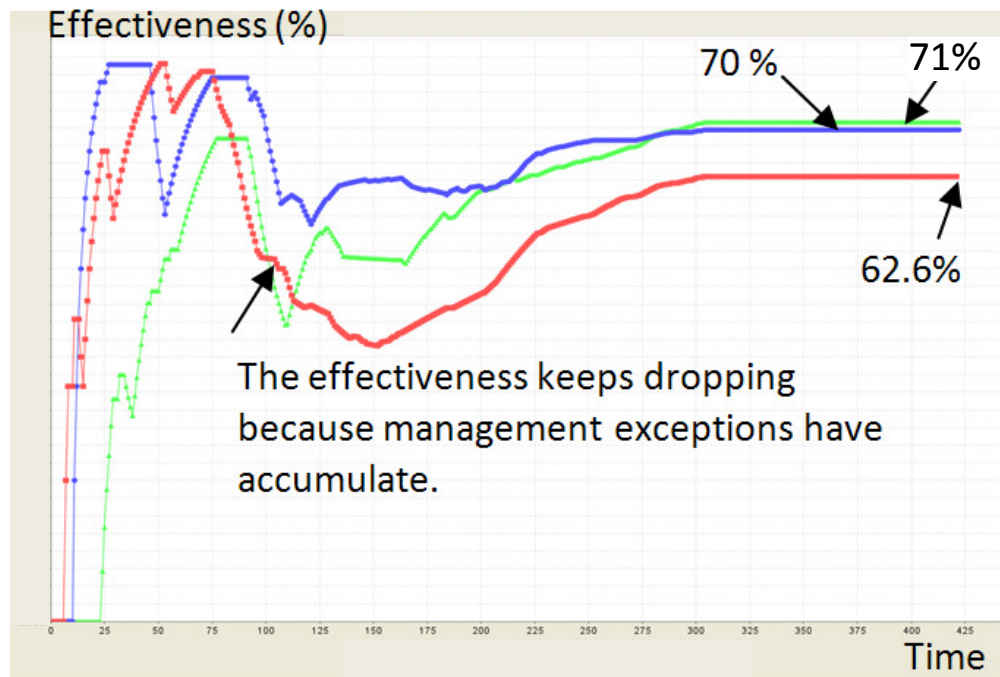
(1) Less meetings



(1) More meetings

**Figure 6.7** Accumulative effectiveness of bidding work (scenario 3)

**Figure 6.7 Cont'd**



(2) Less meetings

#### **6.1.5. Interpretation of simulation results**

Case study 1 examines the cooperation related issues of an estimating team on DBB projects. In particular, the simulation experiments investigate the implications of a variety of managerial actions. Results indicate that cooperation related behaviors and processes are a critical connection between management actions and team performance in estimation development. For example, in one simulation experiment, two types of coordination preferences of managers are compared, i.e., whether current workloads of team members are considered when assigning new tasks to them. Results indicate that if a manager always assigns tasks to faster staff, in hopes that the entire job would be finished more quickly, the ultimate result is often the opposite. The entire estimation job may actually

last longer if the workload is not well balanced among team members. Certain staff might become over stressed and a variety of behavioral responses, such as complaining, may be triggered. These responses add up to nonproductive time because additional efforts are needed to solve the conflicts. In another experiment, the function of meetings is examined. It reveals that in some cases, more meetings are helpful to improve team productivity, although the meetings themselves take time. One possible explanation is that meetings may enhance mutual understanding between team members, resolve conflicts, and reduce unnecessary communication. The entire team is gathered in one place and problems may be solved effectively. But if the decision maker over relies on meetings to solve perceived exceptions (i.e., situations not expected or planned), the team might become excessively inefficient because too much time would be spent on meetings. Clearly, according to the findings in this case study, the relationship between managerial actions and ultimate team performance is nonlinear - any managerial actions taken by the decision maker could cause a series of unexpected behavioral responses from the team, which in turn alters the expectations of the team performance. This relationship depends on the characteristics of the jobs, particular organizational context, and behaviors of every member on the team.

In case study 1, no significant empirical data existed. A what-if scenario simulation examined the possible outcomes of adopting certain managerial actions/strategies. However, these managerial actions/strategies were not actually applied in the company when the case study was ongoing. For example, the simulation compared the results of



different task assignment preferences. But in reality, it is very difficult, if not impossible, to actually change managers' behaviors and to observe the consequences.

Therefore, face validation was used in this case study to validate the findings of the simulation experiments. As addressed by Banks and colleagues (2005), face validation is used when there is a lack of empirical data, or for the purpose of reducing development cost. It is achieved by “*consulting people knowledgeable about system behavior on model structure, model input, and model output. Use any existing knowledge in the form of previous experience*” (Banks et al. 2005).

Two principals of company D were interviewed, focusing on their perceptions of the model's validity and the simulation results. All possibilities reflected in the simulations were fully discussed. They both agreed with the reasonableness of the simulation findings. In particular, they agreed that: (1) adding one extra job might influence the completion of other undergoing jobs; (2) workload is a critical decision point for managers and thus, the proper level of work balancing is needed; and (3) meetings benefit the company by solving issues, enhancing mutual understanding, clarifying needs, and encouraging communication. One principal indicated that the VOICE simulation experiments were useful for investigating performance enhancement opportunities in the company.

## **6.2. Case study 2: Inter-team cooperation in project proposal development**

Case 1 investigated interpersonal cooperation within a single project team. Case study 2 extends the investigation to interpersonal cooperation in a cross-functional context where

the institutional and psychosocial conditions become more complex. In particular, VOICE is utilized to examine the implications of goal incongruence in cross-functional cooperation during project proposal development.

### **6.2.1. Case overview**

The case study was conducted with a large construction company (denoted as Company Z). The major focus of Company Z is the construction and maintenance of power plants, nuclear plants and refinery facilities. In order to enhance its competitive ability in the EPC market (Engineering, Procurement and Construction), Company Z acquired an engineering design firm (denoted as ZENG) a couple of years ago to design of all of Z's new EPC jobs. At Z, proposal development is the sole responsibility of a Z's project proposal team (i.e., estimating team). But because of the specialty of work, Z's proposal team highly relies on the technical and quantity information from ZENG to form estimates and develop proposals.

A series of face-to-face interviews with those in key roles at Company Z (including vice president, department heads, coordinators and estimators) highlighted cooperation difficulties between Z's proposal development team and the engineering team of ZENG. Z's estimators found it increasingly difficult to obtain necessary information from their ZENG counterparts. Problems included "late reply" and "inaccurate or incomplete information" from the engineering team, "lack of trust," "lack of integration of processes," "different technical terms and knowledge set," etc. As a result, frustration was spreading

in the proposal team and had led to serious performance issues. When asked about the reasons, although specific answers were different, most respondents attributed the current cooperation issues between the proposal and engineering team to “unclear statement of the objectives,” “misuse of definitions” and “very different understanding of needs.” This suggests that the “incongruent targets between proposal team and the engineering team” was the biggest driving factor of the inefficient cooperation between the two teams. A survey (N=34) to process owners in company Z confirmed the above observations and highlighted key concerns/interests in the company, which constitute the major themes of the simulation experiments using VOICE:

- **Effects of goal incongruence:** 65% of respondents believed the cooperation issues between the proposal team and engineering team to be based on “different focuses” of the two teams. In particular, the engineering team’s goals were structural integrity, constructability and robustness. The proposal team’s goals were accurate and efficient proposals. Such goal differences could lead to a divergence in behaviors.
- **Additional implications of time pressure:** 91% of the respondents claimed time to be the first priority of proposal development. They believed that a sense of time pressure can significantly affect the quality and efficiency of the cooperation between two teams.
- **Additional implications of task dependence:** 78% of the respondents claimed task dependency to be a critical variable in the cooperation between the proposal

team and the engineering team. It was believed that a higher level of task dependence requires more cooperation between two teams.

- **Additional implications of micro-management:** the management of Company Z wanted to understand if the goal congruence is mitigated or amplified by the management style of managers, especially their preference for micro-management.

### **6.2.2. Model assumptions**

In order to model this case in VOICE, a set of assumptions were made. First, it was assumed that expectations in this case are mainly generated by information exchange. When a project proposal team member is working on proposal development, he/she requires intensive information from the engineering team. An exception occurs when available information is insufficient for the responsible proposal team member to perform the task (Galbraith 1973), which leads to additional coordination, communication or reassignment activities at the immediate expenses of time and cost or quality. Goal congruence plays a vital role in this process, which is demonstrated in the difference of the perceptions of behavioral standards and ranking of management criteria (Thomsen et al. 2005). Goal congruence can affect the quality and amount of the appropriate information contributed by the engineers because a higher magnitude of goal congruence is anticipated to enhance the understanding among team members (Witt 1998). Thomsen et al. (2005) model goal congruence as a percentage, with 100% being the most congruent condition and 0% being the least. This case study uses the same definition and assumes a

linear relationship between goal congruence and information quality/amount exchanged between an engineer and a project proposal team member.

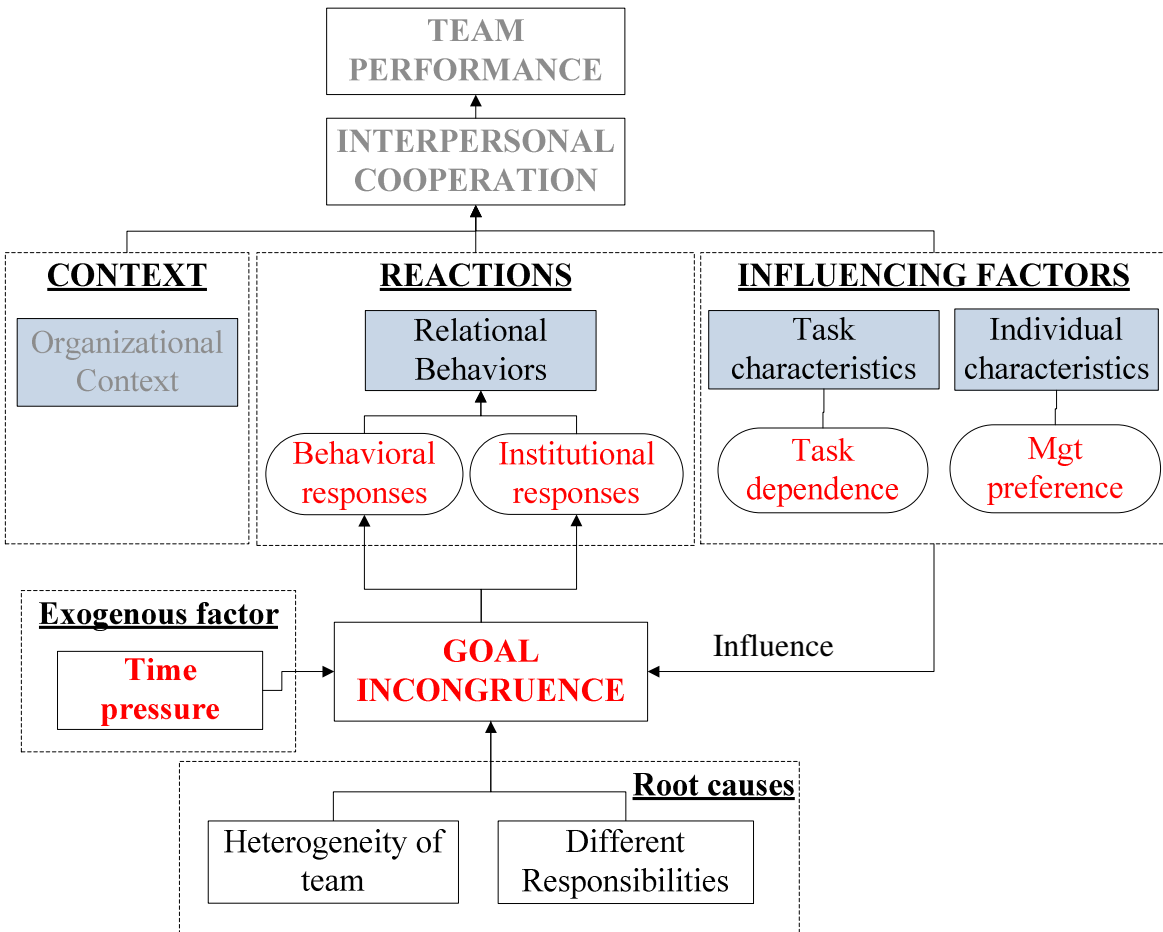
Second, it was assumed that a variety of micro-level behavioral and instructional responses occurs when goals between two teams are incongruent. The most immediate effect is the behavioral responses of team members, including: (1) non-conformance: Kunz et al. (1997) found that if no identical goal exists, team members tend not to follow the approaches which others might favor or prescribe. The final performance may be imperfect if such non-conformance is not remedied; (2) passive responses: team members may react to the consequences of goal incongruence, including correcting or reworking tasks with perceived errors and counteracting against nonproductive non-conformance. These behavioral responses will improve the quality of decision making, but at the direct expense of time and cost (Witt 1998); and (3) proactive responses: new evidence from psychosocial research (e.g., experimental findings) finds that goal incongruence at the intermediate level encourages actors to study a wider range of alternatives, and finally, mutually agreed upon solutions might be found (Jehn 1995; Amason 1996). It also facilitates the understanding and interpretation of the needs pertaining to the considered solutions and encourages actors to participate and fully engage in the pursue of better achievement of common goals (Kunda 2006). In addition to behavioral responses, evidence reveals that goal incongruence may lead to a variety of institutional reactions, including “coordination effort,” “selective authority delegation,” “monitoring,”

“steamrolling” and, “politicking.” Thomsen et al. have an excellent discussion on the details of these institutional reactions (Thomsen et al. 2005).

Third, it was assumed that a series of factors may intensify or mitigate the effects of goal incongruence. This has been supported by numerous organizational and psychosocial findings. The most influential variable is task characteristics. Evidence suggests that a high level of interaction and task dependence intensifies the influence of goal incongruence (Schmidt and Kochan 1972; Gladstein 1984; Jehn 1995). The other influential factor for goal incongruence is individual personal traits, such as competence, experience and managerial preferences (Mintzberg 1983; Pfeffer 1994; Smith et al. 1994; Burton et al. 1998; Thomsen et al. 2005). For example, Pfeffer (1994) found the competence level of an individual to determine the manner of coping with conflicts from goal incongruence – people with higher expertise tend to appeal to a higher authority instead of negotiating with the counterpart. Thomsen et al. (2005) suggest that managerial preference may mitigate or amplify the effects of goal congruence.

Ultimately, the consequences of goal incongruence – behavioral and institutional responses, influential variables including task and individual characteristics – determine team performance, including time (Thomsen 1998), quality (Thomsen et al. 2005) and others. Under the proposed conceptual framework, behavioral and institutional responses triggered by goal incongruence can be modeled by the relational behaviors of VOICE. Task characteristics and individual attributes serve as the influential factors.

Organizational context forms the context of the micro-level behavior processes. These interactions ultimately determine the quality of inter-team cooperation and then the performance of proposal development. Figure 6.8 summarizes the modeling of case 2 with the proposed framework.



**Figure 6.8** Modeling case 2 with the proposed conceptual framework

### 6.2.3. Model development

#### 6.2.3.1. Inputs

A survey was conducted to 34 process owners in company Z to collect data with respect to task characteristics and individual traits. Then probability distribution functions (PDFs) were fitted to the data. Table 6.1 summarizes the PDFs of key variables. For more details of the input data, please refer to Appendix 2.

**Table 6.1** Fitted PDFs of key variables of individuals and proposal development task

<b>Task characteristics</b>	<b>PDF</b>
Work amount	Normal (24, 4)
Priority	Uniform (1, 3)
Difficulty	Uniform (1, 3)
Authority level	{ 1,2,3 }~{ 60%, 30%, 10% }
Dependence	Poisson (4.06)
Information	Normal (0.2, 0.15)
Starting address	Ceiling (Uniform (0,5))
<b>Individual information</b>	<b>PDF</b>
Competence	Two peaks normal
Capacity	Normal (120, 8)
Processing error	Normal (0.05,0.01)
Position level	1,2,3
Assigning preference	3
Exception handling time	Lognormal(0.335,0.769)
Quality/Info threshold	Johnson SI (2.29, 0.92)
VP's exception threshold	20
Reactions to exceptions	Report 45% Return 45% nothing 10%

Monte Carlo simulation was performed in this case study to fully investigate the implications of goal congruence. Therefore, task dependence was used as a probability that determines whether a newly generated task can be processed or not when preceding

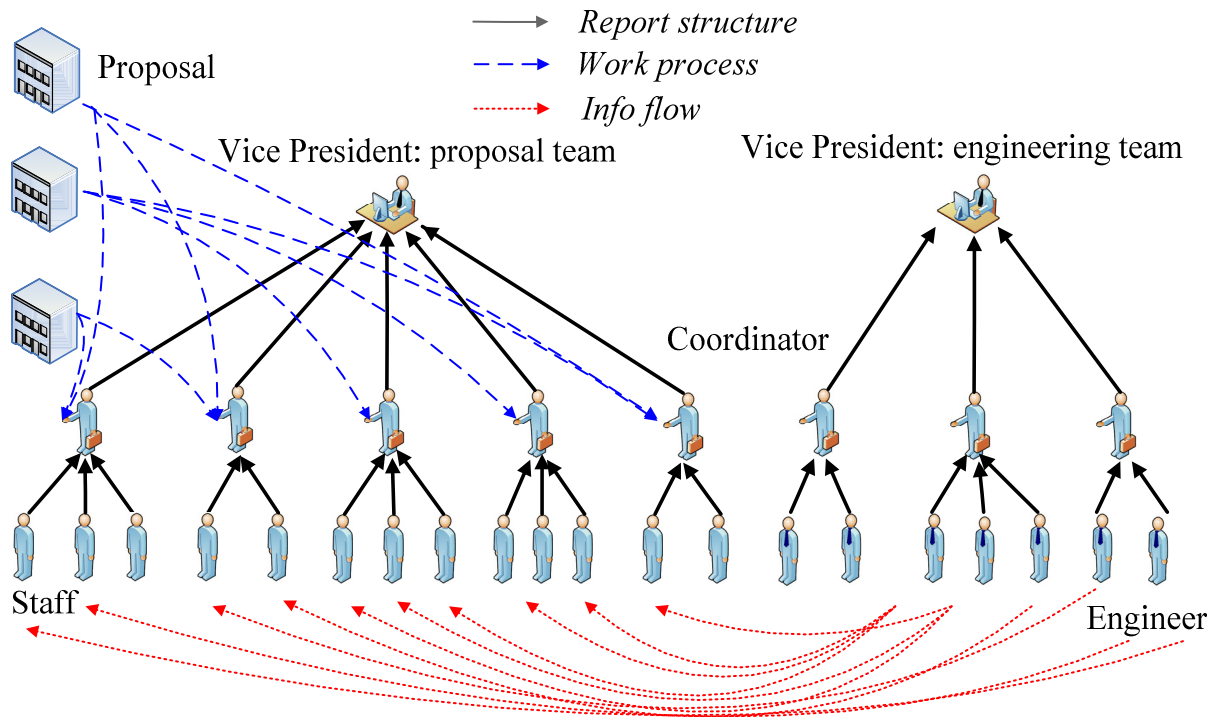


tasks are ongoing. Task information refers to a percentage of the amount of information, where 100% means perfect fulfillment of the information need. Because the assigning preference of the manager/coordinator is not the interest of this case study, it assumes that all coordinators will assign tasks to the staff with the least work pressure, which makes sense in most cases.

#### *6.2.3.2. Process*

Based on the responsibility description, there are four roles in a proposal team: (1) Vice president of proposal team, whose responsibilities include the overall control of estimating work of all projects, the validation and approval of the final proposal, and initializing and organizing meetings within the proposal team or across teams; (2) Proposal coordinators, who integrate the craft estimates, check and validate the estimates submitted by discipline estimators, coordinate tasks, and solve the conflicts between estimators and/or between estimating team and engineering team. The estimating coordinator's job is done on a project basis; (3) Estimators of all disciplines. Their jobs include quantity take-off, productivity study (estimating the work hour/quantity), pricing (quoting prices from vendors), validation of estimate (comparing estimates with historical similar jobs) and estimate entry (entering the final craft estimates to the information system); and (4) Engineers, who do not participate in the proposal directly, but provide necessary design information to the proposal development team. The simulation considers a simple scenario, i.e., five proposal coordinators and corresponding staff members are

considered in the simulation. Such simplification will not affect subsequent experiments and analyses, since it well represents the work settings of the proposal team. Similarly, the engineering team's structure is also simplified to capture the actual work environment (Figure 6.9).



**Figure 6.9** Snapshot of the simulation (case study 2)

#### 6.2.3.3. Outputs

Four performance indicators are selected as the index in the experiments, including efficiency, effectiveness, quality and work related pressure.

## **6.2.4. Simulation results**

### ***6.2.4.1. Experiment 1: Direct influence of goal congruence on team performance***

This experiment is interested in the influences of goal congruence on the performance of the proposal development in two situations: (1) without time pressure, and (2) with time pressure. The first scenario aims to reveal the pure influence of goal congruence, while the second scenario is also interested in the additional implications of time pressure perceived by team members. Following Pruitt and Drews' findings (1969), a sigmoid function was used to measure time pressure.

#### **Influence on efficiency**

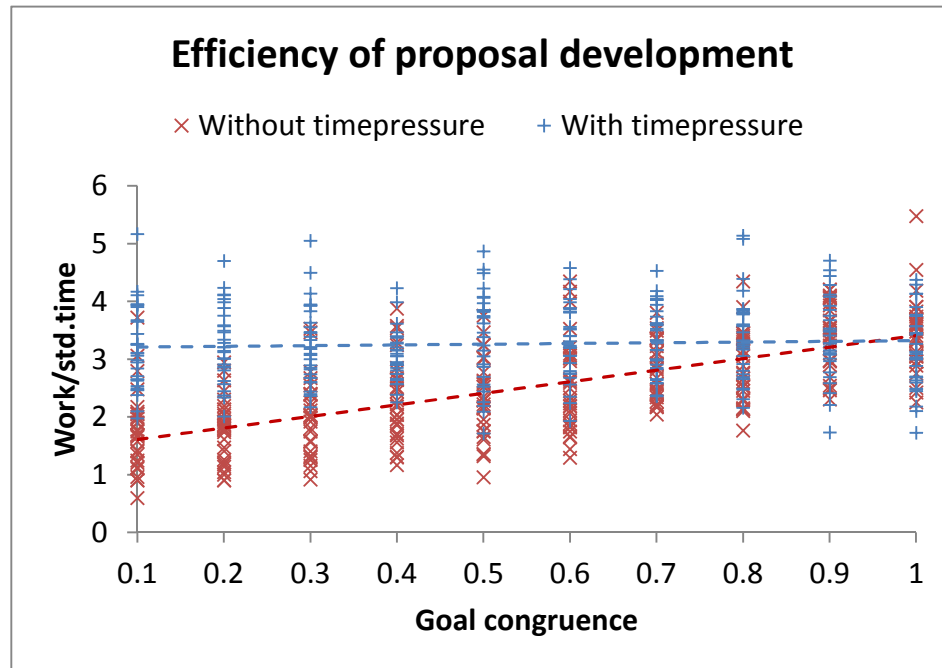
The simulation results (Figure 6.10) indicate there is a strong linear correlation between the magnitude of goal congruence and the efficiency of the proposal development without time pressure ( $p\text{-value} < 0.0001$ ). A quadratic or cubic ANOVA test does not improve the corresponding F-ratio. This conclusion contradicts some previous studies (such as Thomson et al, 2005) where a nonlinear relationship was observed. A possible explanation is that in proposal development, the quality and amount of the information exchanged is strongly tied to the magnitude of goal congruence, which amplifies the influences of goal congruence on work efficiency (influences of other factors are weaker).

Figure 6.10 indicates that the efficiency of proposal development becomes more stable under different levels of goal congruence ( $p\text{-value} = 0.893$ ) when time pressure is

noticeable. When the level of goal congruence is smaller than 0.8, values of efficiency with time pressure are significantly larger than those without time pressure. The distinction between the values of efficiency becomes ignorable when the level of goal congruence is greater than 0.8 (Table 6.2). This finding means time pressure can significantly improve the efficiency of proposal development under a lower level of goal congruence. This observation has been ignored in practice – according to the interviews to the key decision makers of company Z, it was believed that sharing goals between the proposal team and the engineering team can always improve productivity of the proposal development. However, this simulation experience found if there is a specific deadline for proposal development, proposal team member would somehow work really hard to meet the deadline, no matter how well the goal has been shared between them and engineers. As a result, efficiency remains in a certain level. VOICE revealed some facts that could be easily missed by key decision makers.

**Table 6.2** ANOVA tests under different levels of goal congruence (efficiency)

GC	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
F-ratio	62.26	92.59	56.45	22.89	31.31	18.86	13.67	8.89	0.073	3.04
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	0.0042	0.7879	0.0866

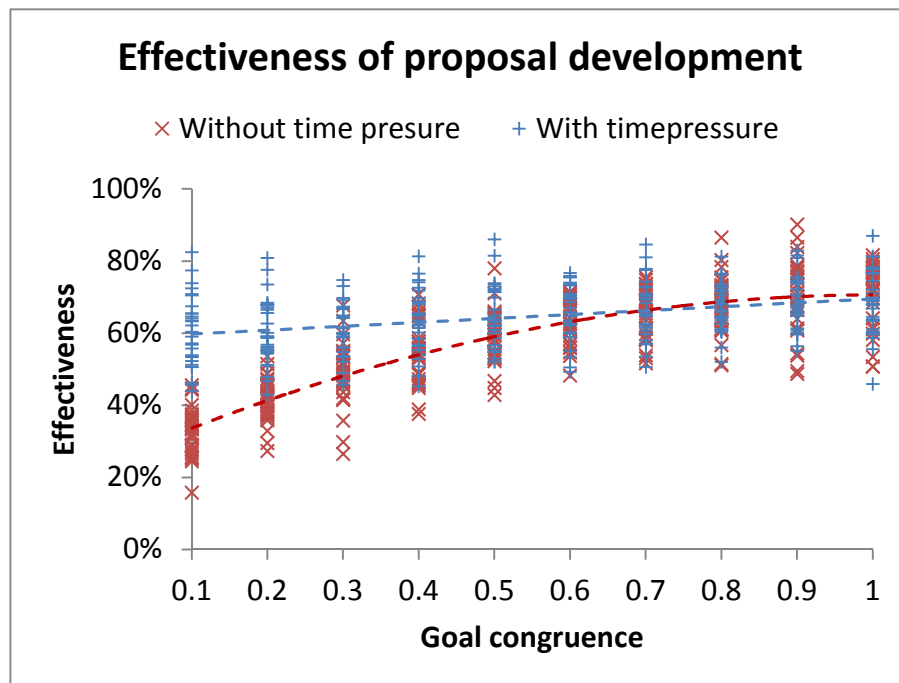


**Figure 6.10** Influence of time pressure on efficiency of proposal development

### Influence on effectiveness

The influence of goal congruence on effectiveness of the proposal development is nonlinear when there is no time pressure (Figure 6.11). An ANOVA analysis indicates a quadratic relationship gives better p-value ( $p\text{-value} < 0.0001$ ). Increases to work effectiveness will slow down when goal congruence becomes bigger, and when goal congruence is over a certain level (0.8 in this case), the effectiveness becomes stable. It means the marginal diminishing effect exists in the additional contribution of goal congruence to work effectiveness. A realistic interpretation of this finding is that when goal congruence is greater than a certain level, the additional effectiveness gained is attributed more to other factors than to shorter communication and routine time.

However, effectiveness becomes more stable when time pressure matters (Figure 6.11;  $p$ -value=0.782), meaning the influence of goal congruence becomes ignorable. Again, the distinction between the effectiveness is significant when the level of goal congruence is smaller than a certain level (0.6). This indicates that time pressure offsets the influence of goal congruence. This finding has provided an explanation to a previous observation, that goal congruence doesn't benefit efficiency of the proposal development when time pressure matters. It is likely that in order to meet the deadline, the proposal team tends to reduce nonproductive time such as quality monitoring, meetings and communication. As a result, the effectiveness of the proposal development keeps in a relatively high level. This experiment has revealed the link between human behaviors and the global team effectiveness, which could be easily ignored in practice.



**Figure 6.11** Influence of time pressure on effectiveness of proposal development

**Table 6.3** ANOVA tests under different levels of goal congruence (effectiveness)

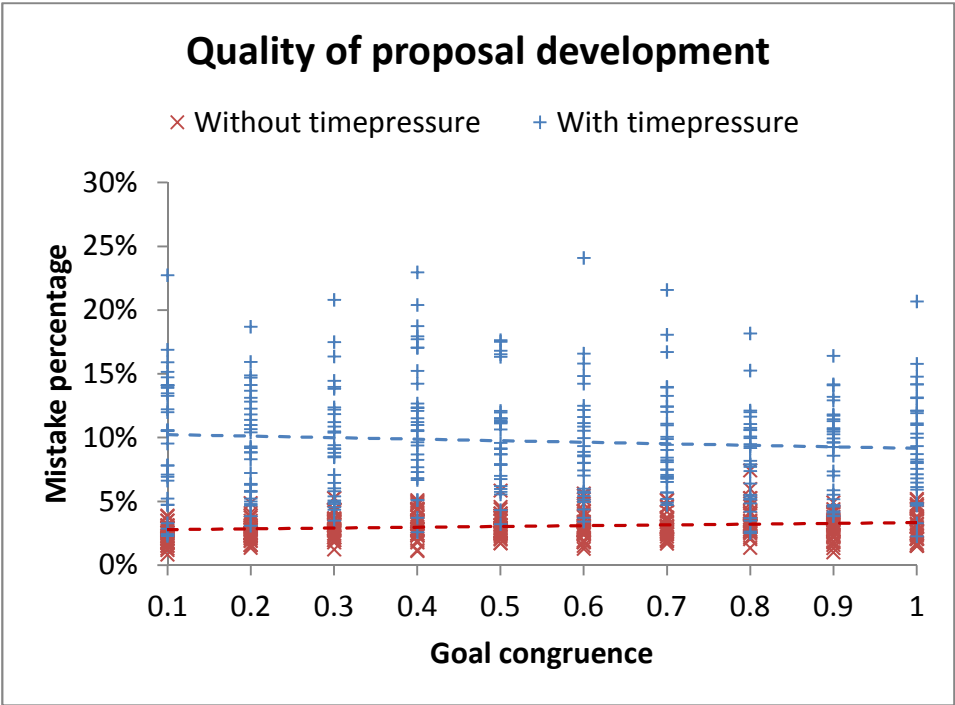
GC	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
<b>F-ratio</b>	169.20	92.47	32.13	12.23	10.56	3.37	0.58	0.01	0.80	1.49
<b>p-value</b>	<0.0001	<0.0001	<0.0001	0.0009	0.0019	0.0714	0.4487	0.9243	0.3743	0.2277

### **Influence on quality**

No significant relationship was observed ( $p\text{-value}=0.5521$ ) for the influence of goal congruence on the quality of proposal development when there is no time pressure (Figure 6.12). This observation contradicts previous studies, such as Thomson et al. (2005). The reason is that proposal development is highly quality-driven: in the studied case, the coordinators were responsible for the accuracy of the developed proposal and always set a rational expectation for the estimates. If the estimates highly diverged from a reasonable range according to the historical data, the coordinators would request a re-work or correction in most cases. This may sacrifice the efficiency of proposal development for additional communication and routine activities, but it ensures the quality of the final proposal (Figure 6.12).

This experiment demonstrated that time pressure significantly increases the risk of committing more mistakes in proposal development (Figure 6.12). As shown, the average mistake percentage tripled under time pressure. This observation is true at all levels of

goal congruence with a small statistical significance level (Table 6.4). This means that improvements to the efficiency and effectiveness of proposal development sacrifice the expected quality of the delivered proposal. This observation is corresponding to previous findings about the change to the efficiency and effectiveness when time pressure matters. Because there is a deadline to meet, the proposal team members tend to reduce time for quality monitoring by relaxing their quality threshold. The consequence is the team will to commit more mistakes. This is another example that how human behavior and attitude can affect team performance under different situations. Such a finding builds on an overall consideration of the micro-level processes and the transition to the global performance, which can be hardly captured by human experience.



**Figure 6.12** Influence of time pressure on quality of proposal development



**Table 6.4** ANOVA tests under different levels of goal congruence (quality)

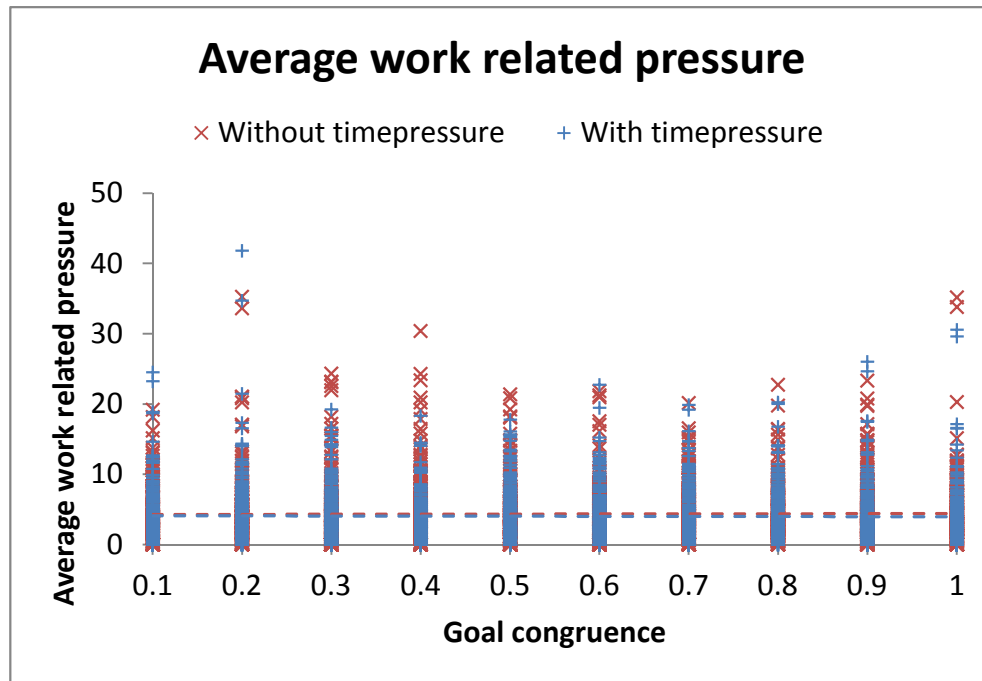
GC	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
F-ratio	62.41	70.41	72.52	85.63	90.14	62.55	73.72	43.89	75.48	66.21
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

**Influence on work related pressure**

Another finding of this experiment reveals that goal congruence may hardly affect the work pressure of employees when there is no time pressure (p-value=0.6769). Figure 6.13 shows that the values of the averaged work pressure of all proposal team members stay within a stable range between 0 to 50. A further investigation was conducted for each team member. Results indicate for individuals, the level of goal congruence remains ignorable compared to work pressure, most likely because work pressure is mainly determined by task characteristics (such as work amount and difficulty). Improved goal congruence is not helpful for reducing the accumulated work amount of the proposal team members.

An experiment was also conducted to check if the averaged work related pressure changes when time pressure matters. The result offer a negative answer – there is no significant difference between work related pressures under the two scenarios, i.e., with/without time pressure (Figure 6.13). This finding has revealed a fact that couldn't be easily found, that work pressure is mainly dependent on the technical characteristics of tasks, such as task

amount and difficulty. Although an F test is passed when goal congruence equals 0.4 (Table 6.5), it can be interpreted as a systematic error due to the relatively small size of the sample.



**Figure 6.13** Influence of time pressure on averaged work pressure

**Table 6.5** ANOVA tests under different levels of goal congruence (averaged work pressure)

GC	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
F-ratio	0.50	0.12	0.98	13.01	0.098	0.65	0.087	0.042	0.18	0.055
p-value	0.4793	0.7292	0.3227	0.0003	0.7549	0.4205	0.7682	0.8377	0.6716	0.8147

#### *6.2.4.2. Experiment 2: Additional implications of task dependence*

This experiment investigates whether task dependence has additional implications for performance, considering the existing effects of goal congruence. Recent findings of organizational science have revealed that task dependence may intensify or offset the effects of goal congruence (Schmidt and Kochan 1972; Gladstein 1984; Jehn 1995; Thomsen et al. 2005). To examine this, a series of sensitivity analyses were conducted.

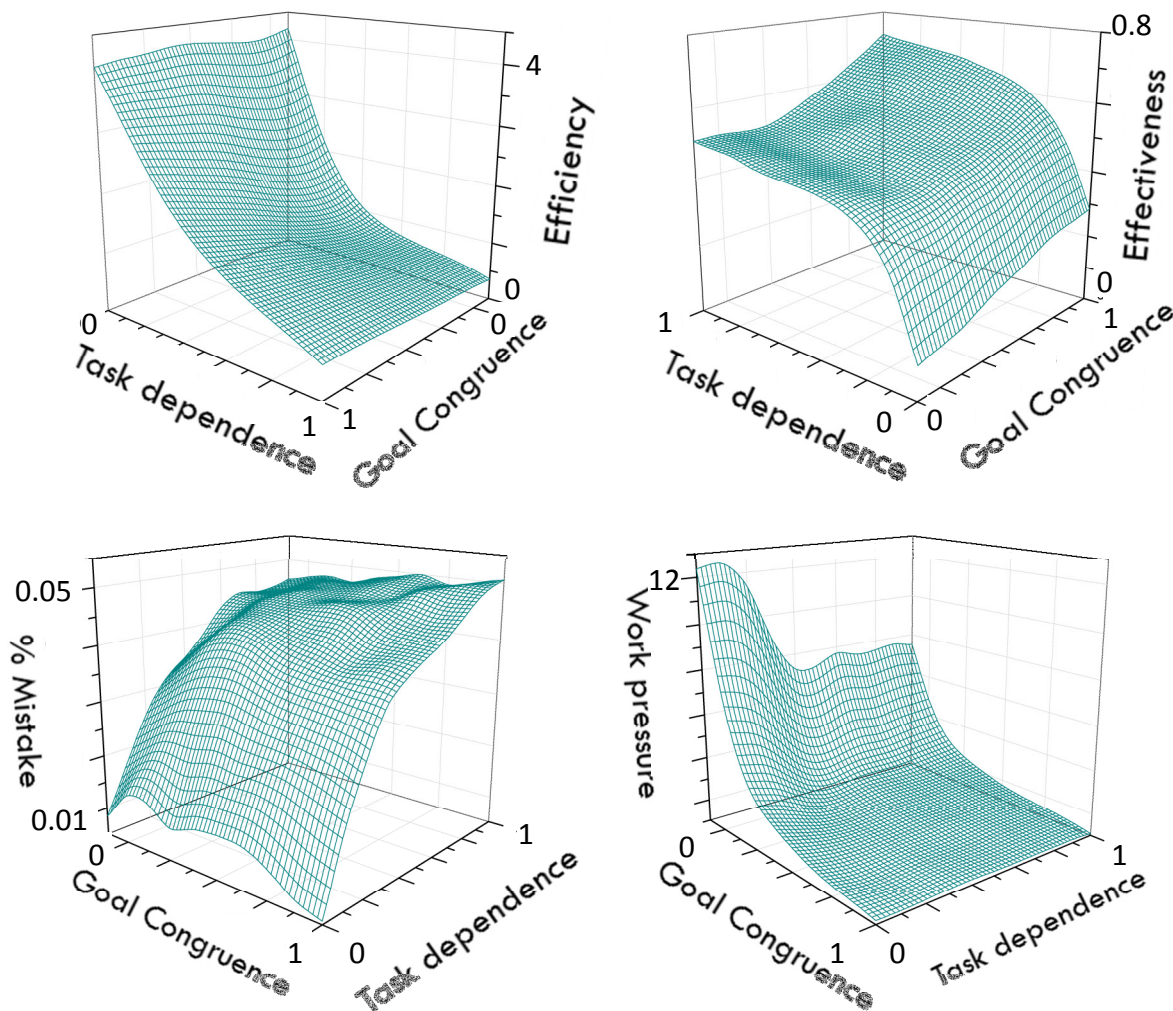
##### **Influence of goal congruence + task dependence**

Figure 6.14 shows the combined influence of goal congruence and task dependence. It indicates that task dependence exerts stronger influences on the efficiency, effectiveness and quality of proposal development ( $p\text{-values} < 0.0001$ ) compared to goal congruence. One interpretation can be made from a technical standpoint: higher task dependence means tasks can hardly be processed concurrently and thus, it is associated with longer waiting times. This further reduces the efficiency and effectiveness of proposal development. It also suggests that if tasks are more dependent on one another, there is a bigger chance that more mistakes will be committed. However, like the finding in experiment 1, task dependence can hardly affect the work pressure of team members.

##### **Amplifier of goal congruence**

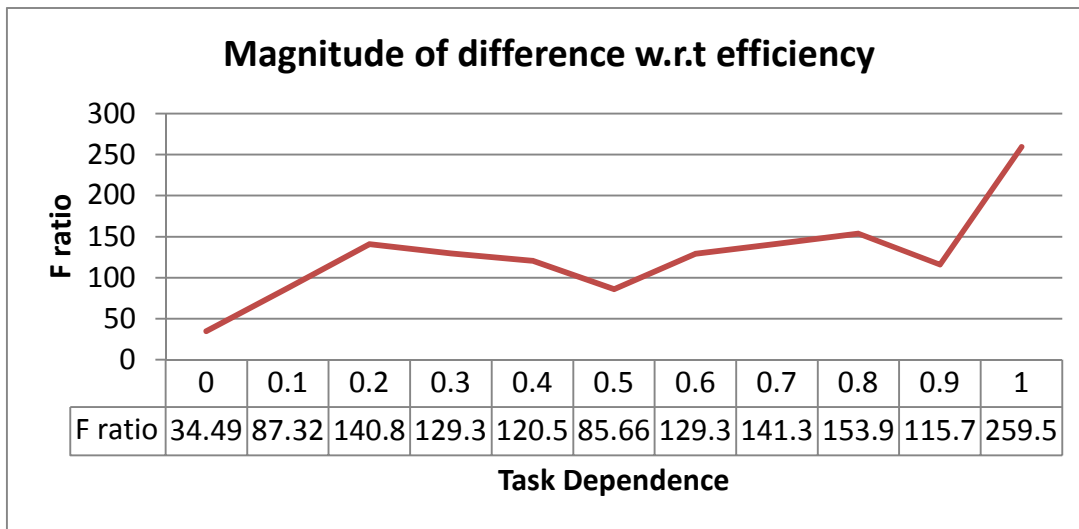
Then, a series of ANOVA tests were performed to check if task dependence intensifies or mitigates the effects of goal congruence, as concluded by the literature. The result shows

that the F ratio tends to become bigger when level of task dependence increases (Figure 6.15). Since the F ratio is an indicator showing the significance of difference, it can be interpreted that **the difference of efficiencies under different levels of goal congruence are amplified**. What's worth noting, to reach this finding requires an overall consideration of multiple factors including behavioral (e.g., goal congruence) and technical (e.g., task dependence) factors. It can be regarded as an emergent phenomenon since it is the consequence of the interactions of multiple factors.



**Figure 6.14** Influence of goal congruence and task dependence

This conclusion is consistent with previous studies, such as the findings of Thomson et al. (2005). Similar findings were obtained with respect to effectiveness of proposal development (results are not shown in this thesis). However, the effects of goal congruence on the quality of proposal development can hardly be altered by task dependence. This is also associated with the quality expectation set by the coordinators.



**Figure 6.15** Influence of task dependence on changes to efficiency under different levels of goal congruence

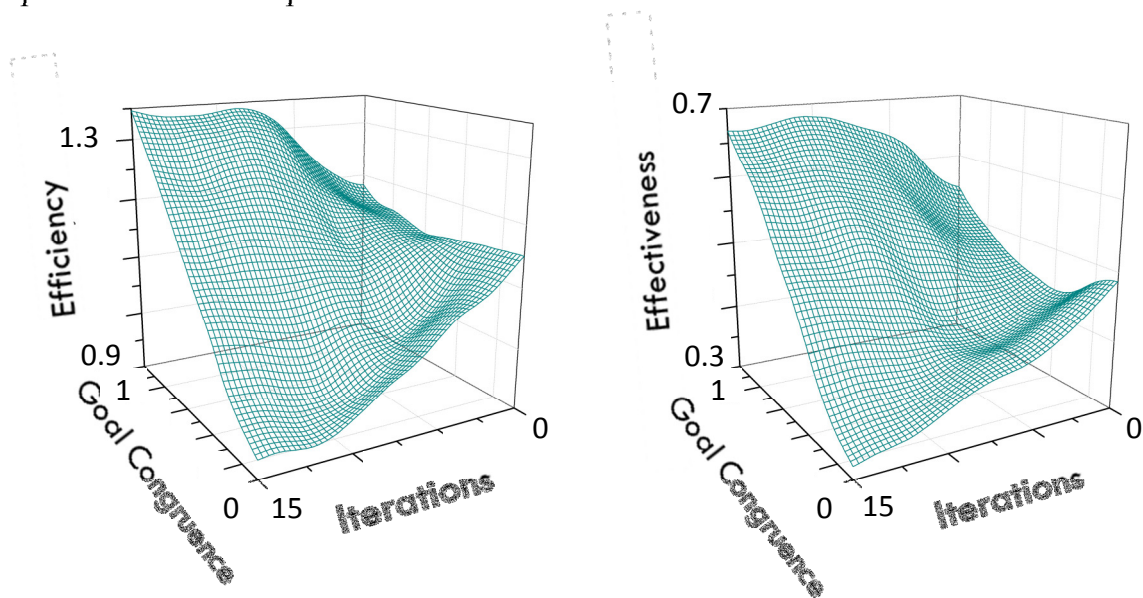
#### 6.2.4.3. Experiment 3: Additional implications of micro-management preference

Management styles can be grouped into two categories according to how coordinators involve themselves in the decision making and managerial actions; the categories are micro-management and not (Mintzberg 1983; Burton et al. 1998). Micro-management is the custom of being heavily engaged in the daily affairs and specific tasks of subordinates while the opposite is giving a degree of autonomy to subordinates. This experiment

examines the additional implications of micro-management. The magnitude of micro-management is measured with the acceptable number of iterations for information exchange before raising the issue to coordinators (Pfeffer 1994; Kristof-Brown and Stevens 2001). A smaller acceptable number of interactions means the coordinators prefer to micro-manage.

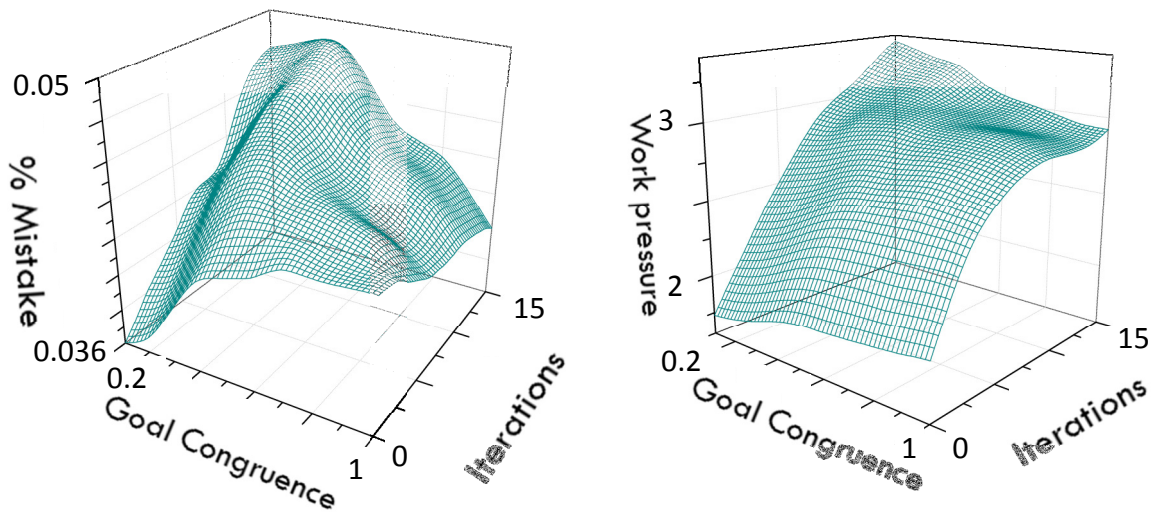
### **Influence of micro-management + goal congruence**

Figure 6.16 demonstrates the combined influences of goal congruence and micro-management preference (acceptable number of iterations) on performance. Micro-management and goal congruence between teams together can alter the shape of performance landscapes.



**Figure 6.16** Influence of goal congruence and micro-management

**Figure 6.16 Cont'd**



A further examination with Figure 6.16 and ANOVA analysis (Table 6.6) found that micro-management's influence shows different features under different levels of goal congruence:

- **Efficiency:** The influence of micro-management on efficiency changes according to level of goal congruence. When goals are less congruent between two teams (0.1 and 0.2), micro-management can help improve efficiency. But when goals are highly congruent between two teams (0.8 and 0.9), too much micro-management indeed hurts efficiency. Otherwise, there is no significant relationship between micro-management and efficiency. The effects of micro-management on efficiency might be opposite depending on the level of goal congruence. In practice, it means that if the proposal team and the engineering team share the same goal, the coordinator should give more freedom to the team members to handle exceptions in order to improve productivity. In contrast, the coordinator should get involved more in the team's daily issues if the goal is different between

two teams. This is the consequence of the interaction between goal congruence and micro-management, and affected by the emergent process from these bottom behaviors to overall team performance. It supports that behavioral and attitudinal factors can significantly affect project team performance. Such relationship is difficult to conceal by pure experience.

- Effectiveness: The effect of micro-management on effectiveness also depends on level of goal congruence. When goals are less congruent, such as at a level of 0.1 or 0.2, micro-management improves effectiveness. Otherwise, micro-management sacrifices effectiveness. This indicates that micro-management helps with effectiveness only when goals are incongruent. Again, it is an example of how behaviors and attitudes of project team members may lead to unexpected team performance.
- Quality: Result shows that autonomy sacrifices quality in most situations. Micro-management can always help reduce mistakes. However, this is not true when the goals of two teams are highly congruent (e.g., greater than 0.9). In this case, micro-management will slightly increase the chance of committing more mistakes. This indicates that when teams share the same goals, micro-management leads to mistakes. The relationship between quality of the proposal development and micro-management is nonlinear, depending on the level of goal congruence. Such nonlinearity can be regards as an emergent property of the cooperation between



the proposal team and the engineering team since it is a result of the interactions of cooperative processes, and lead to unexpected finding.

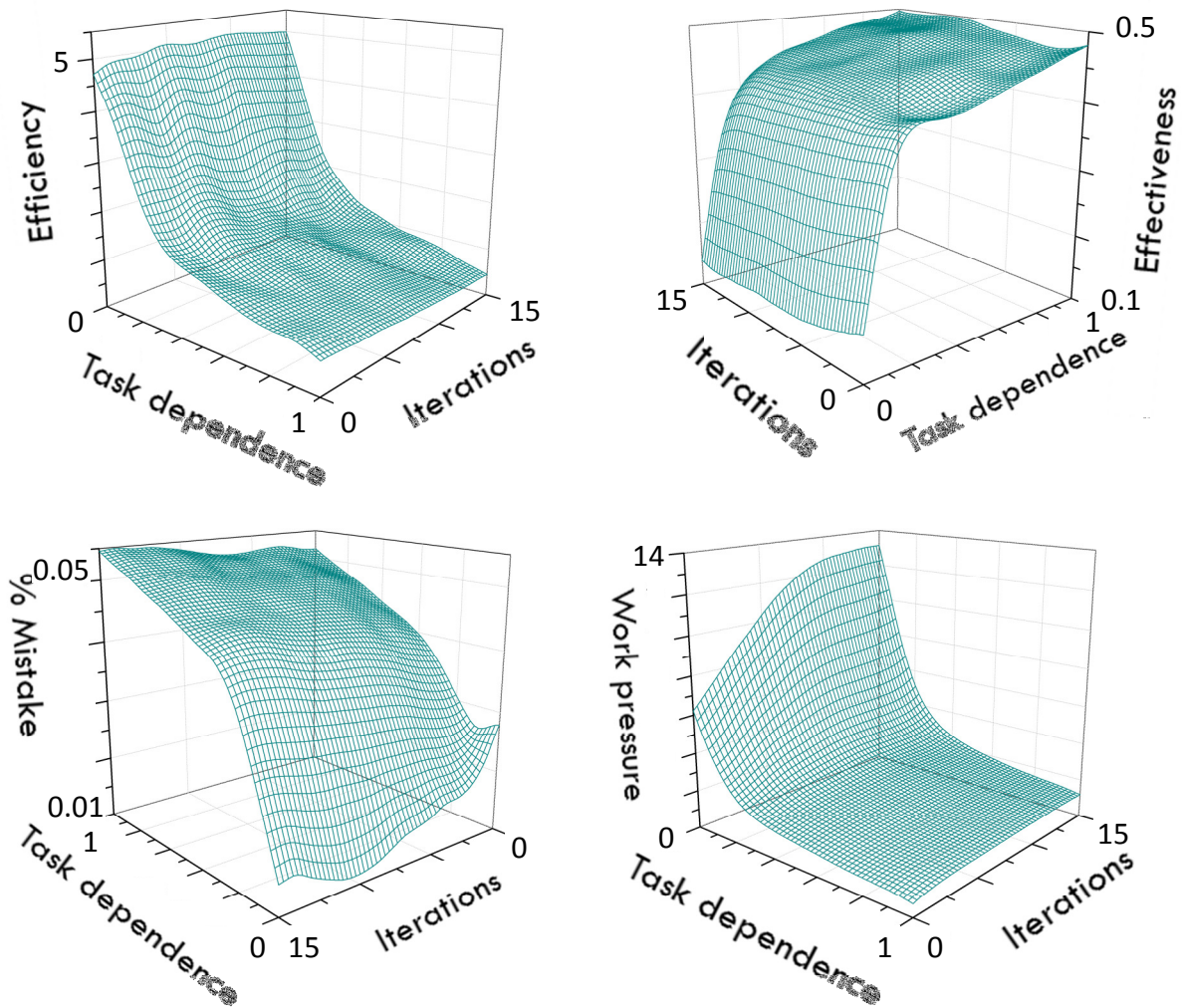
- Work related pressure: the ANOVA indicates there is a significant relationship (p-value<0.0001) between micro-management and work related pressure at each level of goal congruence: less micro-management or higher level of autonomy for the staff means a higher level of work related pressure.

**Table 6.6** p-values of micro-management's influence under levels of goal congruence

<b>Congruence</b>	<b>Efficiency</b>	<b>Effectiveness</b>	<b>Quality</b>	<b>Pressure</b>
<b>0.1</b>	<0.0001*	<0.0001*	<0.0001*	<0.0001*
<b>0.2</b>	0.0002*	<0.0001*	<0.0001*	<0.0001*
<b>0.3</b>	0.0064	<0.0001*	<0.0001*	<0.0001*
<b>0.4</b>	0.3628	<0.0001*	<0.0001*	<0.0001*
<b>0.5</b>	0.3477	<0.0001*	<0.0001*	<0.0001*
<b>0.6</b>	0.479	<0.0001*	0.0134*	<0.0001*
<b>0.7</b>	0.1075	<0.0001*	0.8255	<0.0001*
<b>0.8</b>	0.1533	<0.0001*	0.3698	<0.0001*
<b>0.9</b>	0.0003*	<0.0001*	0.2294	<0.0001*
<b>1.0</b>	0.0024*	<0.0001*	0.0001*	<0.0001*

### **Influence of micro-management + task dependence**

The experiment also examined the combined impacts of micro-management and task dependence on performance. Figure 6. 17 demonstrates the results of uncertainty analysis based on 52,800 simulations.



**Figure 6.17** Influence of goal congruence and micro-management

An examination of Figure 6.17 and the ANOVA reveal the differing effects of micro-management under different levels of task dependence (Table 6.7).

- **Efficiency:** the influence of micro-management becomes less noticeable when task dependence is considered. Only when tasks are very independent (task dependence is 0 through 0.2), is micro-management able to improve efficiency; otherwise, it exerts no influence. This indicates that micro-management is beneficial only when tasks are highly dependent. This finding has demonstrated the interaction between

technical factor (task dependence) and behavioral factor (micro-management), and highlighted the influence on project team performance. It supports that different aspects of cooperation in construction settings may act together to generate unexpected performance.

- Effectiveness: similar to efficiency, the influence of micro-management on the effectiveness of proposal development is not significant when task dependence is considered. Again, this finding requires the consideration of both technical aspect of proposal development and behavioral aspect of management. VOICE provides a possibility to quantify the combined influences of interdependent factors of cooperation.
- Quality: autonomy sacrifices quality. When coordinators prefer the autonomy of team members, the team will commit more mistakes. Worth noting, however, is that the opposite trend occurs when task dependence equals 0, and is due to the abnormal data points in the simulation.
- Work pressure: ANOVA does not show a significant relationship between micro-management and work related pressure under most task dependence levels. Only when tasks are highly independent (dependence is smaller than 0.4) do the results show that micro-management can reduce work related pressure.

**Table 6.7** p-values of micro-management's influence under levels of task dependence

Dependence	Efficiency	Effectiveness	Quality	Pressure
0.0	<0.0001*	<0.0001*	0.003*	<0.0001*
0.1	0.0027	<0.0001*	<0.0001*	<0.0001*
0.2	0.0343	0.0238*	<0.0001*	<0.0001*
0.3	0.0789	0.0862	<0.0001*	0.0253*
0.4	0.1237	0.1658	<0.0001*	0.0448*
0.5	0.3364	0.0822	<0.0001*	0.1864
0.6	0.6238	0.1561	0.0134*	0.3762
0.7	0.1595	0.1231	0.0013*	0.4579
0.8	0.4423	0.0684	0.0002*	0.2688
0.9	0.5864	0.0402*	0.0002*	0.3357
1.0	0.3522	0.0355*	0.0052	0.4238

#### 6.2.5. Interpretation of simulation results

This case study extends the investigation to interpersonal cooperation in a cross-functional context where psychosocial conditions become more complex, especially as the implications of goal congruence become obvious. Several findings are as follows.

First, the simulation finds goal congruence to be an influential factor for team productivity, but negligible to the work quality and work pressure of the project team. First, a higher level of goal congruence between the proposal team and engineering team significantly improves the efficiency and effectiveness of proposal development. A likely interpretation is that enhanced goal congruence improves the mutual understanding of objectives, definitions and needs between two teams, and encourages proactive participation of the engineers in proposal development. This in turn reduces the need for additional coordination, and increases the quality of each information exchange between engineers and proposal team members. To be noted, further investigation finds that time pressure

can alleviate the effects of goal congruence, in that efficiency and effectiveness under different levels of goal congruence show little difference, unlike that observed in scenarios without time pressure. This is because, under serious time pressure, team members tend to be more tolerant of the quality of obtained information and/or tasks, and coordinators are inclined to reduce the frequency of coordination. These behavioral changes indeed improve the efficiency and effectiveness of proposal development, although at the expense of quality. Such findings highlight the positive role of aligning goals between different teams in improving team productivity. On the other hand, however, goal congruence exerts no immediate influence on the quality of proposal development and does nothing to the work pressure of team members. Proposal development is highly quality-driven: coordinators are responsible for the accuracy of the developed proposal and always set a rational expectation for the estimates. If the estimates greatly diverge from a reasonable range according to the historical data, the coordinators will request a re-work or correction in most cases. This ensures the quality of the final proposal at an immediate cost of the efficiency of proposal development, due to additional communication and routine activities. Although contradicting previous findings, such as the work done by Thomson et al. (2005), this conclusion makes reasonable sense in this case study. Another finding reveals that goal congruence hardly affects the work pressure of the employees. This indicates that work pressure is mainly determined by task characteristics, such as the work amount and dependence. Therefore, improved goal

congruence is not very helpful in improving work quality or balancing employees' work load.

Second, in certain cases, micro-management can provide several benefits to a project team, including increased efficiency and effectiveness, improved work quality, and reduced work pressure of team members; but this is true only when certain behavioral and technical conditions are met. The simulation results find that micro-management improves the efficiency of the project team only when goal congruence between the proposal team and the engineering team is at a relatively low level. In other words, when the two teams obviously diverge in targets, micro-management may help improve productivity. However, when goals between teams gradually become congruent, the benefit obtained from micro-management starts to decrease. When goals are highly congruent (e.g., greater than 0.8), micro-management indeed reduces the efficiency and effectiveness of teamwork. On the other hand, micro-management has relatively consistent effects on other performance indicators, including work quality and work pressure of team members. It was found that micro-management can improve the quality of project teams in all cases, except when goals are highly congruent. This indicates that more frequent involvement from a higher level of management can help quality control. The other finding is that micro-management balances the workload between employees and thus reduces the work pressure. These findings indicate that the effects of micro-management are very contingent on the behavioral and technical conditions of a project

team, suggesting that the adoption of micro-management should be built on a prudent evaluation of the environment.

Third, task dependence can significantly affect the productivity and work quality of the project team; it is able to alter the effects of goal congruence and micro-management.

Task dependence is a crucial factor for understanding inter-team cooperation in proposal development. On the one hand, the simulation results find task dependence to be a significant predictor of efficiency, effectiveness, and quality. If tasks are more dependent, the team is less productive and commits more mistakes. This is understandable from an empirical perspective, since dependence often means additional efforts for communication and coordination, a bigger chance of mistakes and conflicts. On the other hand, task dependence may affect the effects of goal congruence and micro-management. Simulation results found that the efficiency difference between levels of goal congruence becomes bigger when tasks are more dependent. In contrast, the effects of micro-management are more significant when tasks are more independent. This finding highlights task dependence to be a vital point of decision making in project team management, especially when managerial and/or behavioral changes are planned.

## **6.3. Discussion**

### **6.3.1. General findings of simulation studies**

The simulation experiments were conducted based on two case studies, as described in previous sections of this chapter. These experiments investigated realistic issues

pertaining to interpersonal cooperation in construction project teams. In particular, three categories of topics were investigated in these simulation experiments, namely technical, behavioral and managerial:

- Technical: focused on the technical components of interpersonal cooperation and their influences on project team performance. Typical topics include the implications of task characteristics, such as task dependence.
- Behavioral: investigated the attitudinal preferences and behavioral responses of project team members to different situations, and consequential influence on team performance. Typical topics include trust among team members, goal congruence, and influence of sense of time pressure.
- Managerial: investigated the effects of managerial actions/strategies under the general framework of cooperation in construction project teams. Typical topics include influence of different job acquiring strategies, coordination and communication activities, and managerial preferences, such as micro-management.

The simulation results highlighted the role of interpersonal cooperation in project team performance, either with the inter- or intra-team scenario. In addition, it was found that four constructs of interpersonal cooperation--tasks, individuals, behaviors, and organizational context--all play unique roles in forming cooperation and in turn, they affect efficiency, effectiveness, quality and other performance indicators. The findings of simulation experiments are used to form operational recommendations as follows.



### **6.3.2. Operational recommendations**

Based on the simulation findings, a set of operational recommendations are made as follows. It is worth noting that these recommendations are based on very specific case studies, and therefore, should be considered when similar scenarios are met.

**First, it should be noted that any managerial decisions made by the team decision makers will trigger a series of behavioral reactions of the team members, which might lead to unexpected consequences.** Behavioral reactions could be serious enough to alter the effects of original plans. Sometimes, the effects of certain managerial actions are even counterintuitive. A lesson learned from case study 1 is “balancing,” which plays a vital role in improving the performance of the team in the project planning phase. Specifically: 1) decision makers should balance the total work amount to a level commensurate with the team’s capacity. Otherwise, in some cases one additional job could risk the completion of all other jobs; 2) managers should strive to balance the work load between team members. Otherwise, unexpected behavioral responses might occur, and additional time will be taken for unnecessary coordination; and 3) the function of meetings in enhancing cooperation between team members should be recognized, but the frequency of meetings should strike a balance between the benefit gained and cost of time.

**Second, improving goal congruence between functional units and applying micro-management should be considered simultaneously in order to improve team performance.** On the one hand, encouraging team members to share the same goal is

always helpful for team productivity. A higher level of goal congruence can significantly improve efficiency and effectiveness in proposal development. This directly results in shorter work duration and less cost. But goal congruence helps the quality of proposal development very little. On the other hand, the simulation revealed that micro-management can always help reduce mistakes in the developed proposal and therefore, improve quality. However, it reduces efficiency and effectiveness of the team, especially when goal congruence is improved. In short, improving goal congruence and applying micro-management might offset consequences. As a result, the decision maker must make a strategic decision between the two approaches, according to the specific environment. For example, if the job is highly time driven, a feasible strategy to improve team performance could be to improve the mutual understanding between different functional units on the objectives through more face-to-face communication. But if the job is quality driven, a better strategy might be more involvement of management in routine jobs, adding more quality monitoring procedures.

**Third, decision makers should notice the importance of the technical characteristics of the jobs, especially task dependence, in the effects of any decision on team performance.** Evidence from the simulation experiments has proven task dependence to be an amplifier of the effects of goal congruence but at the same time, it mitigates the influence of micro-management. This finding has a practical value for decision makers. In the case when tasks are more dependent, the decision makers should make a greater effort to improve goal congruence rather than use micro-management; but when tasks are

relatively independent, micro-management is a better choice for improving team performance. In this way, the benefits gained from improved goal congruence or micro-management can be utilized to the maximum.

The results demonstrate that VOICE is an effective decision support tool for project team management, not simply a theoretical investigation tool. It converts realistic scenarios to executable models, where inputs are drawn from empirical evidence. Furthermore, because ABM is utilized, and a GUI is used in VOICE, practitioners will have little difficulty applying VOICE to real world management practices.

#### **6.4. Summary**

In order to illustrate how VOICE can be used to solve realistic cooperation issues in construction project teams, two case studies were introduced in this chapter. Inter-team and intra-team cooperation problems of the two cases were framed using the proposed framework. A set of what-if scenario simulations and exploratory simulations was conducted to quantify the relationship between cooperative behaviors or processes and project team performance. Operational recommendations were offered based on the simulation results.

## **CHAPTER 7: CONCLUSIONS**

This chapter reviews the entire work and provides a constructive and precise evaluation of this research. It identifies the contributions of this research, and addresses the limitations of this research and future agenda to fill the gaps.

### **7.1. Review of the research**

This research stemmed from the recognition of the importance of enhancing cooperation in the construction industry. Accumulating evidence attributes performance issues of the construction industry to the lack of cooperation between project participants, which is described as a reciprocal effort of two or more individuals or organizations acting toward the accomplishment of the common interest. An in-depth review of this research found that existing industrial and academic efforts should be extended for fully understanding cooperation in construction settings. The theoretical gaps can be grouped as:

- A lack of effort to investigate cooperation at individual levels;
- A lack of attention to the behavioral and attitudinal aspects of cooperation in a construction setting;
- A lack of solid evidence for the relationship between cooperation and construction project team performance; and
- A lack of an effective research method to capture the complexity of the studied theme.

In response to the importance of this theme, this research investigated cooperation in construction project teams from an innovative perspective that has been ignored by most

efforts. In particular, it investigated cooperation at the individual level – this research views interpersonal cooperation as the most fundamental cooperation process that determines the quality of a construction project team. As a result, the core of this research is to capture the transition from local dynamics of micro-level cooperative behaviors to global performance of project teams. Unlike most of previous studies in the same topic, it emphasizes the diversity of cooperative behaviors of project team members and the realization of them in different scenarios.

To achieve the research goal, a comprehensive conceptual framework was developed based on an extensive review of literature pertaining to cooperation theory, construction project teams, and exploratory simulation. The proposed framework captures all relevant components of cooperation in a construction setting, including technical factors, individual traits and behaviors, and organizational context. Team performance, e.g., productivity and quality, is assumed to be the result of the interactions among these components of cooperation. On the basis of the proposed conceptual framework, an ABM simulation platform, named VOICE (Virtual Organizational Imitation for Construction Enterprises), was developed for a rigorous theory-based investigation of the micro-level behavioral and attitudinal factors that shape local interpersonal cooperation processes in construction project teams, and their impacts on team performance.

VOICE was used to conduct two in-depth case studies. In the first case study, intra-team cooperation between members of an estimating team in typical DBB projects was

explored. The big question was “How do managerial actions affect cooperative behaviors in a single team and in turn determine team performance in typical Design Bid Build (DBB) projects?” Specifically, the implications of certain managerial actions - job acquiring strategies, coordination activities, and team communication - were investigated under different scenarios. The second case study extended the investigation to a cross-functional context where institutional and psychosocial conditions become more complex. The simulation experiments were performed based on a real scenario between a proposal team and an engineering team in an EPC construction enterprise. The question investigated was “What is the role of goal congruence in the cooperation between members of different teams during project proposal development?” The effects of goal congruence were examined, based on a series of uncertainty analyses. Moreover, the implications of time pressure, task dependence and micro-management were investigated to determine if additional influences were exerted on inter-team cooperation. The findings of the two case studies and corresponding analyses have validated the basic assumption of this research, that cooperation at an individual level plays a vital role in determining the performance of a construction project team in certain cases. This investigation could be nontrivial because there are numerous complex interactions to be captured between components of cooperation. These interactions constitute the transition from local dynamics to global efficacy of a construction project team.

This research does not aim to tune down the importance of previous research efforts. Instead, it attempts to add knowledge to construction studies, from an innovative

perspective, associated with the nature and implications of interpersonal cooperation in construction project teams. It still falls in the research category of enhancing cooperation in construction settings.

## **7.2. Contributions of this research**

This research has made a variety of contributions to the body of knowledge with respect to the cooperation in construction settings. In particular, it builds a stepping stone for the knowledge transformation of cooperation research in construction by providing an innovative investigation approach, and offers a decision support tool for construction companies. The specific contributions are summarized as follows.

**First, this research provides an alternative method for future cooperation studies in construction, i.e., a simulation model to investigate cooperative behaviors at the individual level and micro-level processes in the construction context.** The importance of cooperation in forming high performance construction project teams has been well recognized. But there is a lack of comprehensive framework to capture all relevant elements of cooperation at the individual level in construction project teams. Furthermore, it remains a problem that how to realize a continuous knowledge discovery with an effective investigation method other than surveys and interviews. This research developed a simulation model to provide a more comprehensive view for future cooperation studies in construction. Specifically, the model captures the most fundamental and specific processes that constitute interpersonal cooperation in construction project teams,

including technical factors (task characteristics), behaviors (cooperative behaviors), individual traits and organizational context (reporting structure, work process and information flow). It views cooperation as a synthesized result of the dynamic interaction among these factors. For instance, various simulation experiments conducted in this research have proven cooperation to be a manifestation of the interactions among individuals. Such a method provides innovative insight into the constructs and mechanics of cooperation in construction, and allows the understating and investigation of the dynamics of cooperation that we couldn't access before. In a short, this research models for insights, not numbers.

**Second, the case studies contribute to the cooperation research in construction by highlighting the role of behavioral and attitudinal aspects of cooperation in construction settings when certain conditions are met.** Industry has attempted to understand and solve cooperation related issues from a technical point of view. Efforts have included new contracting strategies and advanced technologies made to foster the collaboration between project organizations. This research proposed an alternative way to encourage cooperation in construction projects, and paid particular attention to the behavioral and attitudinal processes of each project team member. The two case studies found in certain cases project team members tend to adopt very different behavioral actions towards changes in circumstance, which is affected by their psychosocial conditions. These behavioral reactions to the contingencies will, in turn, determine the quality and efficacy of project teamwork. Some experiments indicated that a slight change



to the behavioral preference of the actors, such as the micro-management preference of managers/coordinators in project teams, can significantly affect the final productivity and quality of the team work.

**Third, this research proves ABM to be an effective investigation approach in the studied theme, especially in an era when complexity dominates.** The interactions among components of interpersonal cooperation and project team performance is quite complex, affected by multiple other institutional and environmental factors (such as task dependence). There is no simple answer to the nature of cooperation in construction settings as claimed by previous evidence; instead, the complex interactions of cooperative behaviors and processes should be taken into account. Traditional “top-down” methods have proven insufficient to the studied theme because rules of the entire system are posited even before the investigation. In a temporary and virtual context, considerable information pertaining to cooperative behaviors and processes is missing from the analytical process. ABM, on the other hand, fits into the studied theme very well. It situates an initial population of autonomous heterogeneous agents, i.e., project team members in this case, defines decentralized behaviors, and allows them to interact according to local rules; thereby, it generates (or “grows”) the macroscopic regularity from the bottom up. This is a natural reflection of the cooperation processes in construction project teams. Results indicate that ABM can effectively capture the complexity embedded in cooperation processes of project teams, and is able to reproduce the transition in a bottom-up manner. Plus, attributed to the flexibility of ABM, the model

architecture can be easily tailored to different scenarios. Uncertainty analysis is also a simple function in ABM. The findings of this research add additional credibility to the application of ABM in the construction engineering and management field.

**Last, this research provides construction companies with an innovative decision support tool, VOICE.** It is very easy for decision makers in any construction organizations to measure the performance of a construction project. Also, it is not a nontrivial job to evaluate the micro-level team processes in construction settings such as processing project tasks. However, the link between local processes and global project team performance is contingent on many contextual factors. It is therefore difficult for most decision makers to estimate the likely performance outcome of a team, given complex initial conditions and relationships among these conditions. VOICE is developed in this research to capture the transition from local dynamics of cooperation processes and behaviors to global performance of construction project teams. The two case studies demonstrated that VOICE can be used to examine the influence of local processes, such as micro-management, specific coordination, trust among team members, communication and conflicts, on a project team's performance, including efficiency, effectiveness and quality.

### **7.3. Potential limitations of this research**

Several weaknesses of this research might limit the reasonableness of the findings and the applicability of the conceptual framework. These weaknesses mainly come from the limitation of the research methodology.

**First, the conceptual framework proposed in this research still needs external justification to increase its reasonableness and applicability.** Interpersonal cooperation in construction settings is a multidisciplinary theme building on the knowledge of multiple disciplines, including psychology, organizational science, construction engineering and management. The conceptual framework proposed by this research is mainly based on a literature review solely conducted by the author. Due to limitations of the author's expertise, it is likely that many important aspects/variables are missing from the framework. Furthermore, although the model has been validated against empirical evidence, the possibility still exists that certain assumptions used in the simulation model come from author's inappropriate interpretation of the literature and evidence. Taking the list of cooperative behaviors in VOICE as an example, the author defines and models these behaviors according to a straightforward interpretation of the literature and evidence from the case studies. The rules, at first glance, might make fair sense for the simulation experiments; but there is no guarantee that all necessary psychosocial processes are captured well. Behaviors are investigated separately in VOICE, but they might be interdependent in reality – coordination frequency of a coordinator might be the result of trust between him/her and other team members; micro-management preference might

depend on the manager's competence. Overlooking these interlinks among cooperative behaviors could distort the analysis results. Simplification is a natural requirement of a modeling study, but such simplification should ensure that the fundamental structure of the real system is preserved. This research needs to do more work to justify this.

**Second, more empirical evidence is required to improve the generalizability of the findings.** As a small scale research, the empirical evidence used in the simulation model development and investigation is from only two case studies. Moreover, both case studies are only about cooperation in the project planning phase (one discusses the estimating effort, the other discusses proposal development). This is mainly due to the limited resource that the author could access. Indeed, a construction project is a multi-phase effort, from project planning to project closeout. The cooperation in any project team could occur in home office and project sites. To fully understand the nature and implications of cooperation in construction settings, a representative project phase should be considered. In addition to "phase" consideration, the impacts of project type, contracting strategies, delivery systems and other project and organizational characteristics pertaining to a construction project are not ignorable. This research simplifies the external environment and focuses on a narrow scope, which limits the generalizability of the findings.

**Third, the selected cooperation related issues/problems investigated in the simulation experiments hardly satisfy the full need for reality-based data and thus, hurts the model's usefulness.** Due to the need for accessible resources and length limitation of this

dissertation, only selected cooperation related issues/problems have been investigated in this research. Although these issues/problems are directly identified by practitioners, in that they (issues/problems) are critical to the success of their teams, cooperation related issues/problems in reality could be much richer and more diverse. Critical points of decision could happen in all links of cooperation processes, including organizational, procedural, behavioral, and cultural implications. In fact, numerous studies have already proven the importance of cooperation components in different circumstances. Therefore, future work should incorporate more cooperation related issues/problems in construction settings to improve the usefulness of the developed model.

#### **7.4. Future agenda**

A future agenda is proposed to address the limitations as discussed previously:

- **Refine the current conceptual framework for interpersonal cooperation in construction setting to capture a richer pool of behaviors and reflect interdependent psychosocial processes.** Talents from all relevant disciplines – psychology, sociology, organizational science and other engineering domains – will be introduced for future research efforts. The participation of subject matter experts would help refine the current conceptual framework to reflect realistic interdependent psychosocial processes to a better degree. In addition, the current list of cooperation behaviors will be extended, based on new evidence, to develop a bigger pool of behaviors for the simulation model. The ultimate goal is to

develop a “library of cooperative behaviors” specified for construction organizations, with detailed representation framework and models. By smart selection and combination of these behaviors, future use of VOICE might be to model the comparable complexity in reality.

- **Extending the investigation to consider complete project phases and scenarios.**

More empirical evidence will be collected and integrated into the framework in the hope that the cooperation processes in an entire project life cycle could be captured by the investigation. Moreover, representative scenarios, such as cooperation issues in different project delivery systems, are also expected in future investigations. In such, VOICE can be enhanced to be a generic investigation tool pertaining to cooperation in construction settings. Notably, the basic conceptual framework might need to be tailored to reflect the differences between project phases and scenarios.

- **More advanced analysis methods will be used to enhance the analytical ability**

**of VOICE.** At present, VOICE can support uncertainty analysis. This is helpful to examine the variation of simulation outputs, and uncover the relationship between determinants and observations. However, uncertainty analysis helps little to compare between critical determinants of problems in terms of their contribution to uncertainty, especially when the number of variables considered in the study is quite large. Global sensitivity analysis (GSA) is a better option for the analytical function of VOICE. As an advanced uncertainty analysis method, GSA has

received increasing interest of scholars from different disciplines, especially in environmental science. It decomposes the unconditional variance of the model into terms due to individual factors, plus terms due to interaction among factors (Chen et al. 2005), and therefore, it performs better in revealing the structure of a problem. The challenge of introducing GSA into VOICE is the development of the interfaces across platforms.

This dissertation builds a stepping stone for knowledge transformation about cooperation in the construction context. It is expected that better approaches to improve the performance of construction projects and project teams can be discovered based on the contributions of this dissertation.

## **APPENDICES**



## APPENDIX 1: INFORMATION ABOUT CASE STUDY 1

### A1.1 Data collection instruments

#### *Surveys*

(A sample of three survey templates; N=8)

---

#### **To whom it concerns,**

Thank you for considering participates in this research study!

Contemporary construction project teams are mostly labeled by adversarial relationships, a lack of transparency, and mistrust. This affects team's capability to deliver projects to the client in a reliable and predictable manner. As addressed by many industry wide reports, a real challenge of the construction business is how to encourage project participants to work together effectively. A major source of the ineffectiveness of construction project teams is the lack of interpersonal cooperation between project participants, which is described as a reciprocal effort of two or more individuals act towards the accomplishment of the common interest. Scientific and industrial evidence has proven that interpersonal cooperation across the companies and within the construction company both influence the performance of a project team. Interpersonal cooperation, on the other hand, is a complex consequence of many interacted factors, including personality, work settings, organizational hierarchy, and daily work-related activities etc. To fully understand the interpersonal cooperation in construction project teams, it demands a closer investigation to these relevant factors. This study aims to investigate and reproduce how interpersonal cooperation is built in construction project teams, and what is its influence on team performance using computer simulation.

We appreciate and highly value your cooperation in this research. The investigation results will only be used for the research and education purpose in School of Planning, Design and Construction (SPDC) at MSU; all the information will be classified and kept confidential subjected to Federal and MSU regulations (for more detail, please refer to "Informed Consent Form").If you have any concerns or questions about this study, such as scientific issues, how to do any part of it or to report an injury, please contact the researcher.

By clicking "accept informed consent form", you will be transferred to the survey. Thank you for your cooperation.

#### **PERSONAL PROFILE**

**How many work experience do you have? (      )**

**What department are you in?**

- ☐ Board of Management
- ☐ Project Planning (Estimation, Scheduling etc.)
- ☐ Project Control
- ☐ Project Operation (e.g., Project Manager)
- ☐ Finance/Accounting
- ☐ Human Resource
- ☐ Other:

**What level of position are you currently in?**

- ☐ President or equivalent
- ☐ Vice president or equivalent
- ☐ Department head
- ☐ Senior
- ☐ Junior
- ☐ Other:

## **WORK RELATED BEHAVIORS**

**When doing your job, do you follow the following procedures?**

	Never	Seldom	Half-half	Most time	Always
Seeking for project information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Analyzing the potential project	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Set priority among different tasks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Check the quality of the document/task submitted by subordinates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Approve tasks of subordinates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Assign tasks to subordinates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Check the availability of necessary information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Check whether there are too many exceptions in the entire company (e.g., too many complaints)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Initiate meetings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Make record for future reference	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## **WORK RELATED PREFERENCE**

**If self-assess your work performance quality, what is your assessment?**

☐ Excellent

☐ Good

☐ Average

☐ Not so good

☐ Other:

**Mistakes in submitted job are inevitable. If measured as a percentage, how much percentage is unacceptable for you?**

☐ 1%~3%

☐ 3%~5%

☐ 5%~10%

☐ 10%~20%

☐ Other:

**Continued: If you found too many mistakes existing in the work submitted by your subordinates, what would you most likely do?**

☐ Return it to whom prepared it

☐ Re-assign it to another subordinate, e.g., who has better performance quality

☐ Correct the mistakes by self

- ☐ Initiate an emergent meeting for it
- ☐ Depends on how many mistakes
- ☐ Other:

**When necessary information is missing for your current work (e.g., lack of quotes from subcontractors), what would you most likely do?**

- ☐ Query information source
- ☐ Ask subordinates to find necessary information
- ☐ Make judgment based on experience
- ☐ Looking into common source, e.g., means book
- ☐ It depends
- ☐ Other:

**Many management exceptions happen every day, e.g., too many complaints about overloaded work, lack of subcontractors quotes, or too many work performance quality issues. If we simply count these management exceptions, what is the number of exceptions is too big for you (daily)?**

- ☐ 1~5
- ☐ 5~10
- ☐ 10~15
- ☐ 15~20
- ☐ 20~25
- ☐ 25~30
- ☐ >30

☐ Other:

**Continued: If too many management exceptions happened, what would you most likely do?**

☐ Initiate an emergent meeting

☐ Talk to responsible person

☐ It depends on the seriousness

☐ Do nothing

☐ Other:

**Continued: If you decide to initiate an emergent meeting towards management exceptions, how long of such typical meeting (not routine meeting)?**

☐ <1 hour

☐ 1~2 hours

☐ 2 hours ~half day

☐ half day - 1 day

☐ > 1 day

☐ It depends on the seriousness

☐ Other:

### Task information

No.	Task	Processing/lead time (hour)			Priority (0~10) (10: most urgent)	Complexity (0~10) (10: most difficult)
		Min	Likely	Max		

### YOUR COMMENTS

**Please write any comments in the space provided below regarding this survey. Any feedback will be greatly appreciated**

( )

### *Interviews*

---

(Only present key questions to two principals; N=2)

---

Q1: The major issues in your company? Are they cooperation related?

Q2: Can you describe the responsibilities of your employees?

Q3: Can you describe representative activities of principals/managers/staff on a daily basis?

Q4: How many projects can you estimate at the same time based on current resources?

Q5: Do you agree that individual competence/experience/decision process can affect the work efficiency and effectiveness? Linear relationship?

Q6: To accelerate the estimating, what would you or managers do?

Q7: How many management exceptions can you bear? (e.g., too much unnecessary communication) What will you do to solve management exceptions? (Meeting?)

Q8: Frequency and normal duration of your meeting? Do you agree that meetings can enhance the communication, reduce unnecessary actions and misunderstandings?

Q9: Can you verify/validate the model inputs as presented?

Q10: Can you verify/validate the list of work related behaviors as presented?

Q11: Can you verify/validate the simulation findings as presented?

## *Company Documents*

(Only present the list of documents due to confidentiality)

D1: Organizational chart

D2: Estimation flowchart

D3: Time sheets (Jan 2010 through August 2010)

D4: Job description

D5: Other relevant management artifacts

## **A2.2 Model parameters**

### *Projects and Tasks*

Based on the data instruments, necessary model inputs were collected. The following tables show the parameters of three projects used in simulation.

**Table A.1** Task parameters of Project 1 (size=117)

Task	1	2	3	4	5	6	7	8	9	10
Task amount	5	5	10	15	15	10	20	20	25	10
Task difficulty	1	1	1	1.1	1.1	1.2	1.2	1.5	1.2	1
Task priority	1	1	1	1.1	1.1	1	1	1	1.2	1
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	0	1	1	0	1	1	0	0	0
Authority level	1	1	1	2	2	2	1	1	1	1
# of successor	1	1	1	1	2	1	2	1	1	1
Actor address	0	1	0	0	0	1	2	1	1	1
Task	11	12	13	14	15	16	17	18	19	20
Task amount	5	5	10	15	20	15	10	10	5	5
Task difficulty	1	1	1.2	1	0.5	1	1	1	1	1
Task priority	1	1	1.5	1	1	2	1	2	2	1.5
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	1	0	0	0	1	1	0	0	0
Authority level	1	3	3	1	1	1	1	1	1	2
# of successor	1	1	1	1	1	1	1	1	1	0
Actor address	1	1	1	3	3	2	0	2	2	2



**Table A.2** Task parameters of Project 2 (size=115)

Task	1	2	3	4	5	6	7	8	9	10
Task amount	5	9	10	10	15	12	20	10	25	10
Task difficulty	1	1	1	1	1	1	1.2	1.2	1.2	1
Task priority	1	1	1	1	1	1	1.2	1	1.2	1
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	0	1	1	0	1	1	0	0	0
Authority level	1	1	1	2	2	2	1	1	1	1
# of successor	1	1	1	1	2	1	1	1	1	1
Actor address	0	1	0	0	0	1	4	1	1	1
Task	11	12	13	14	15	16	17	18	19	20
Task amount	10	10	10	15	10	15	10	10	5	10
Task difficulty	1	1	1.2	1	0.5	1	1	1	1	1
Task priority	1	1	1	1	1	1	1	2	2	2
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	1	0	0	0	1	1	0	0	0
Authority level	1	3	3	1	1	1	1	1	1	2
# of successor	1	1	1	1	1	1	1	1	1	0
Actor address	1	1	1	3	3	2	0	2	2	2

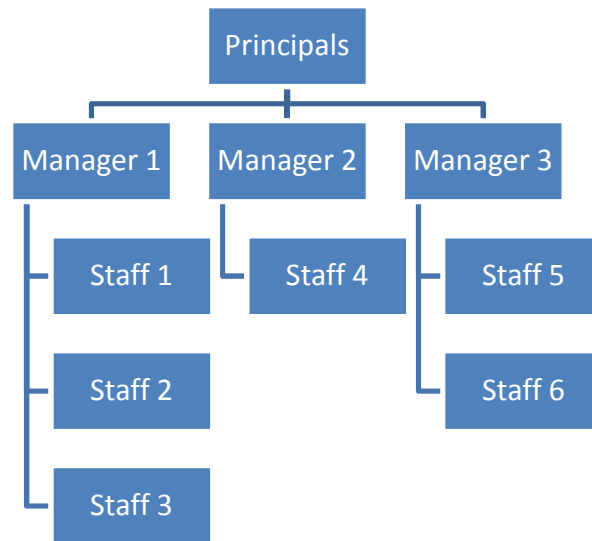
**Table A.3** Task parameters of Project 3 (size=137)

Task	1	2	3	4	5	6	7	8	9	10
Task amount	15	15	10	15	15	10	20	20	30	20
Task difficulty	1	1.2	1	1.1	1.1	1.2	1.2	1.2	1.2	1
Task priority	1	1	1	1.2	1.1	1	1	1.2	1.1	1
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	0	1	1	0	1	1	0	0	0
Authority level	1	1	1	2	2	2	1	1	1	1
# of successor	1	1	1	1	2	1	1	1	1	1
Actor address	0	1	0	0	0	1	4	1	1	1
Task	11	12	13	14	15	16	17	18	19	20
Task amount	5	5	10	15	20	15	10	10	5	8
Task difficulty	1.1	1	1	1	0.8	1	1	1.1	1	1.1
Task priority	1.1	1	1	1	1	1	1	2	1.8	2
Dependency	1	1	1	1	1	1	1	1	1	1
information	0	1	0	0	0	1	1	0	0	0
Authority level	1	3	3	1	1	1	1	1	1	2
# of successor	1	1	1	1	1	1	1	1	1	0
Actor address	1	1	1	3	3	2	0	2	2	2

Individual information is shown in figure 6.2

### **A2.3 Model development**

The following figure demonstrates the sketch of organizational chart of case study 1:



**Figure A.1** Organizational chart of case study 1

Specific model codes can refer to appendix 3: sample codes.

### **A2.4 Outputs**

Charts were generated and documented as shown in chapter 6.

## APPENDIX 2: INFORMATION ABOUT CASE STUDY 2

### A2.1 Data collection instruments

#### Surveys

(Survey template; N=34)

---

##### Introduction

*Obtaining accurate and timely information from the engineering teams at the time of proposal development has historically produced difficulties and process inefficiencies. This survey aims to investigate the causes and possible remedies. Your opinion is extremely important for the success of this survey. Please take 15 minutes to answer the following questions (most are multi-choice questions). Your confidentiality and privacy will be the first priority, and your identification won't be stored or appear in any document.*

##### A. Background information

*Would you please provide background information about yourself?*

How many years of experience do you have as an estimator? (      )

How many years of experience at Z? (                      )

What is your current position? (                      )

Number of years in current position? (      )

What craft is your major area of focus? (                      )

##### B. Problem identification

*Communication with engineering teams at the time of proposal development has historically produced difficulties and process inefficiencies. Could you please provide us your opinions related to these concerns?*

Overall, to what extent do you feel that your performance is affected negatively because of communication issues with the engineering team? Please circle one.

*No Affect (-1-2-3-4-5-) Significant Affect*

Overall, to what extent do you feel that your contact person from the engineering team is meeting your expectations? Please circle one.

*Not meeting any of my expectations (-1-2-3-4-5-) Meeting all of my expectations*

Overall, to what extent do you feel your engineering team counterpart is approachable regarding supporting you in performing your assigned tasks?

*Not at all Approachable (-1-2-3-4-5-) Very Approachable*

Overall, in your opinion, to what extent does the engineering team meet their responsibilities in supporting the estimating process? Please circle one.

*Not meeting their responsibilities (-1-2-3-4-5-) Meeting all of their responsibilities*

I feel the following problems have affected my work efficiency:

- ☐ Late reply from engineering team
- ☐ Inaccurate information from engineering team
- ☐ Different technical terms, labels and knowledge
- ☐ Significant incomplete information from engineering team
- ☐ Others: \_\_\_\_\_

I think the following influence the difficulties and inefficiencies with the engineering team at the time of estimate development:

- ☐ Different focuses
- ☐ Different job responsibilities
- ☐ Different award/evaluation systems
- ☐ Different work objectives
- ☐ Different location

- ☐ Different organizational culture
- ☐ Two separate entities at Z
- ☐ Work procedure issues
- ☐ Lack of effective communication methods/technologies
- ☐ Lack of rules or standard procedures to solve problems
- ☐ Lack of personal social contact
- ☐ Lack of coordinating efforts from upper levels
- ☐ Others: \_\_\_\_\_

How would you change the current work process to better support your estimating task? \_\_\_\_\_

What other issues do you feel are important regarding communication issues with the engineering team? \_\_\_\_\_

### **C. Task-related questions**

*Research suggests the features of a person's work can affect communication. Could you please provide us your opinions about your work?*

To what extent is your task performance dependent on receiving accurate information from engineering team? Please circle one.

*Not at all Dependent (-1-2-3-4-5-) Very Dependent*

To what extent does your task performance impact others in your team?

*Very Little Impact (-1-2-3-4-5-) Significant Impact*

To what extent do you agree that working at the same location with the engineering team could improve communication? Please circle one.

*No improvement (-1-2-3-4-5-) Significant Improvement*

To what extent do you work closely with others in your team to perform your tasks?

*Work independently (-1-2-3-4-5-) Work closely with others*

I typically understand my work objectives and the process to perform my tasks

*Do Not Understand (-1-2-3-4-5-) Understand*

Please describe typical tasks you perform on a daily basis (including a brief description, normal duration and if this task is dependent on engineering team).

Task Name	Task Description	Task Duration	Dependent on engineering team?

#### **D. Personal characteristics-related questions**

*Personal characteristics play an important role in interpersonal relationships. Would you please share your opinion of your personal characteristics?*

To what extent you agree with the following statements. Unless noted otherwise use: (1: Strongly DISAGREE; 5: strongly AGREE):

I frequently do extra things I know I won't be rewarded for, but which make my cooperative efforts with other people more productive. (-1-2-3-4-5-)

I willingly help other individuals, even at some cost to my personal productivity. (-1-2-3-4-5-)

I prefer to work with others in a group rather than working alone. (-1-2-3-4-5-)

When making decisions at work that affect others, I try to take their needs and feelings into account. (-1-2-3-4-5-)

I enjoy discussing my current job with people outside work. (-1-2-3-4-5-)

I rate my job satisfaction as (-1-2-3-4-5-)

I assist others with difficult/heavy workloads, even though it is not part of my job. (-1-2-3-4-5-)

My contact person from the engineering team is typically qualified with sufficient experience and depth of technical knowledge. (-1-2-3-4-5-)

My contact person presents him / her self as an important resource to the team. (-1-2-3-4-5-)

From my experience I rate my engineering counterpart's commitment to the process as *Unacceptable* (-1-2-3-4-5-) *Acceptable*

My engineering counterpart always tries to take my needs and time deadline requirements into account. (-1-2-3-4-5-)

In your opinion, does your engineering counterpart take ownership of the quantity estimate provided to you for inclusion in an estimate? *Not at all* (-1-2-3-4-5-) *Yes*

#### **E. Interaction related questions**

*The following questions are about how you communicate with the engineering team, and your personal response to certain conditions when working on major estimates.*

In my work I use the following ways to communicate with engineering team:

☐ Phone call

☐ Email

☐ Fax

☐ Face-to-Face meeting

☐ Mail

☐ Others: \_\_\_\_\_

The most important ONE communication way:

☐ Phone call

☐ Email

☐ Fax

☐ Face-to-Face meeting

☐ Mail

☐ Others: \_\_\_\_\_

The frequency I officially communicate with engineering team is \_\_\_\_ times / week when we are developing a proposal.

Overall we (me and person from engineering team) spend \_\_\_\_ minutes in each conversation.

The frequency I socially and informally communicate with engineering team is \_\_\_\_ times / week.

Overall, on average, I typically wait \_\_\_\_ hours or \_\_\_\_ days to get response from engineering team.

Overall, it typically takes \_\_\_\_ iterations (times “back-and-forth”) until I get the final information I need.

How often has your engineering counterpart notified you when he/she could not meet a commitment? *Never (-1-2-3-4-5-) Always*

If you cannot get needed information, which of these actions do you typically take? Please mark (1, 2, 3):

☐ Contact the same person again

☐ Seek help from another person in engineering team

☐ Seek help from someone in my team

☐ Contact the supervisor of engineering team

☐ Try to figure out the needed information by myself

☐ Schedule a face-to-face meeting

☐ Others: \_\_\_\_\_

Once you get the needed information, what would you do:

☐ Use the information directly

☐ Carefully check the information before using it



☐ Others: \_\_\_\_\_

Measured in a percentage (100% is the best), what percentage of quality of the information is acceptable in your work? \_\_\_\_\_ (e.g., 90%)

If you believe lack of qualified tasks of others has just affected your work, what action do you typically resort to first:

☐ Raise issues to supervisor

☐ Try to talk to responsible person

☐ Leave it alone

☐ Others: \_\_\_\_\_

How often do you have official meetings with engineering team? \_\_\_\_ (e.g., 1/month)

Regarding improved communications, can you briefly describe the positive results you have experienced from face to face meetings with your engineering counterpart?

\_\_\_\_\_

## **F. Organization and procedure related questions**

Current procedures lead to decisions and outcomes favorable to me.

*Never (-1-2-3-4-5-) Always*

Members of the estimation team are encouraged by supervisors to take proactive action to resolve engineering communication issues?

*Never (-1-2-3-4-5-) Always*

Help is available from the organization (estimation and/or other teams) when I have a problem.

*Strongly Disagree (-1-2-3-4-5-) Strongly Agree*

Rather than being totally dependent on my engineering counterpart to come through when I need assistance, I try to have a backup plan ready.

*Strongly Disagree (-1-2-3-4-5-) Strongly Agree*

I keep close track of my interactions with my engineering counterpart, taking note of instances where he/she does not keep up her/his end of the bargain.

*Never (-1-2-3-4-5-) Always*

#### **F. Open Question**

What else do you want to say regarding the communication difficulties with the engineering team, such as causes, solutions, or your feelings? ( )

#### ***Interviews***

---

(Only present key questions to five key decision makers; N=5)

---

Phase 1:

Q-1: What are the major issues in your team? Are they cooperation related?

Q-2: Amongst the four identified cooperation related issues, which one is considered as the most critical one?

Q-3: Why is the communication/information exchange issue between proposal team and engineering team is important to you?

Phase 2:

Q-1: In general, how long it takes to develop a proposal?

Q-2: Do you and/or your colleagues have to work overtime to get your work done? Do you feel pressure or frustration?

Q-3: What are the major responsibilities of your work?

Q-4: Can you verify/validate the list of work related behaviors as described?

Q-5: To what degree you and/or your colleagues' job are dependent on the engineering team?

Q-6: Do you think the performance of proposal team is affected negatively by engineering team?

Q-7: Can you describe problems/difficulties with engineering team?

Q-8: What are the reasons for the problems you just described?

Q-9: How would you change current work process to better support your estimating task?

### ***Company Documents***

(Only present the list of documents due to confidentiality)

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D-1: Organizational chart

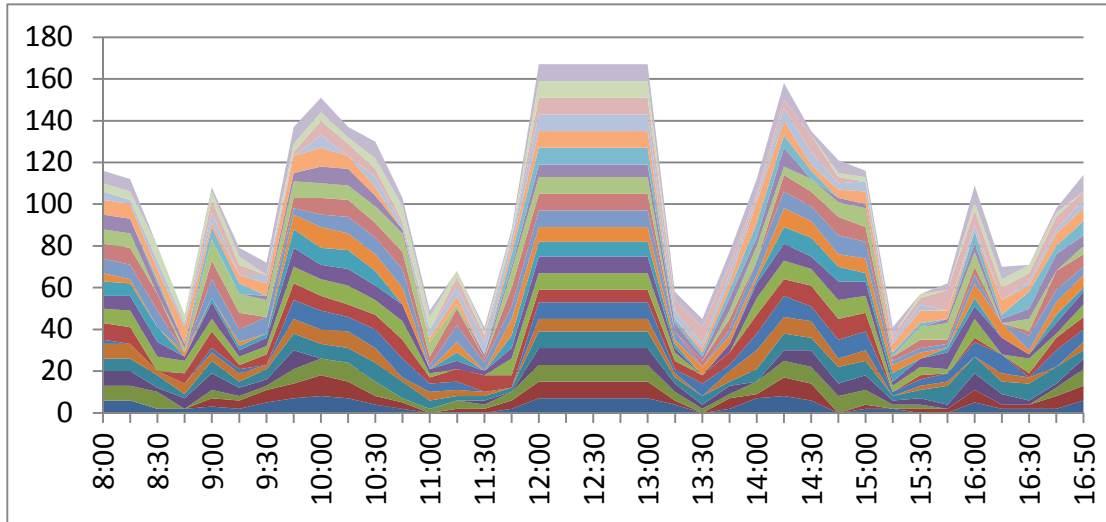
D-2: Proposal development flowchart

D-3: Other relevant management artifacts (e.g., excel pivot table used for communication purpose)

### ***Work Sampling***

---

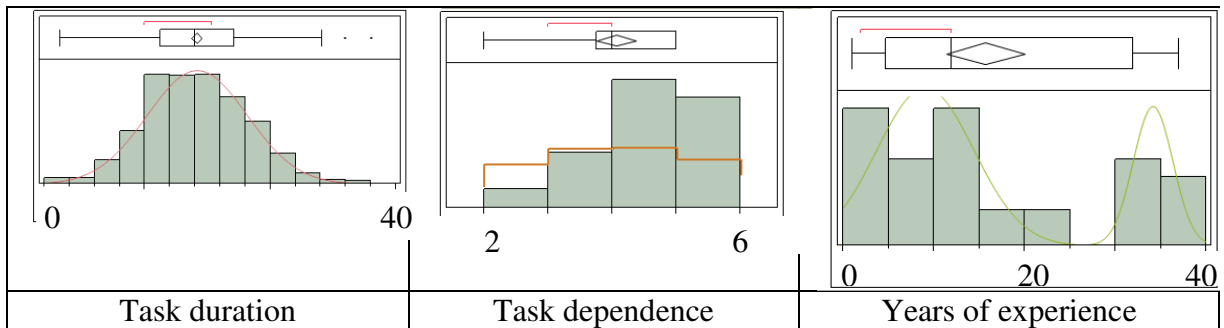
In order to collect actual data about work effectiveness, two approaches were used: 1) survey: in a survey 34 respondents were asked to provide information of their nonproductive activities, i.e., activities not associated with direct processing of tasks, such communication (e.g. phone calls, emails and other communications that are not face-to-face) and waiting time. Frequencies and durations of these activities were finally obtained; and 2) work sampling: the author conducted a work sampling to one of the case study companies for a month on a consecutive basis. Every day, 8 am through 5 pm, the author documented number of people talking face-to-face or in a meeting at every 15 minutes. The results were integrated finally to study the face-to-face communication behaviors of the team members (Figure A.2). It was found in average, team members spent around 20% of their time in “talking”, which is defined as nonproductive in VOICE.



**Figure A.2** Work sampling result of the face-to-face communication in a month

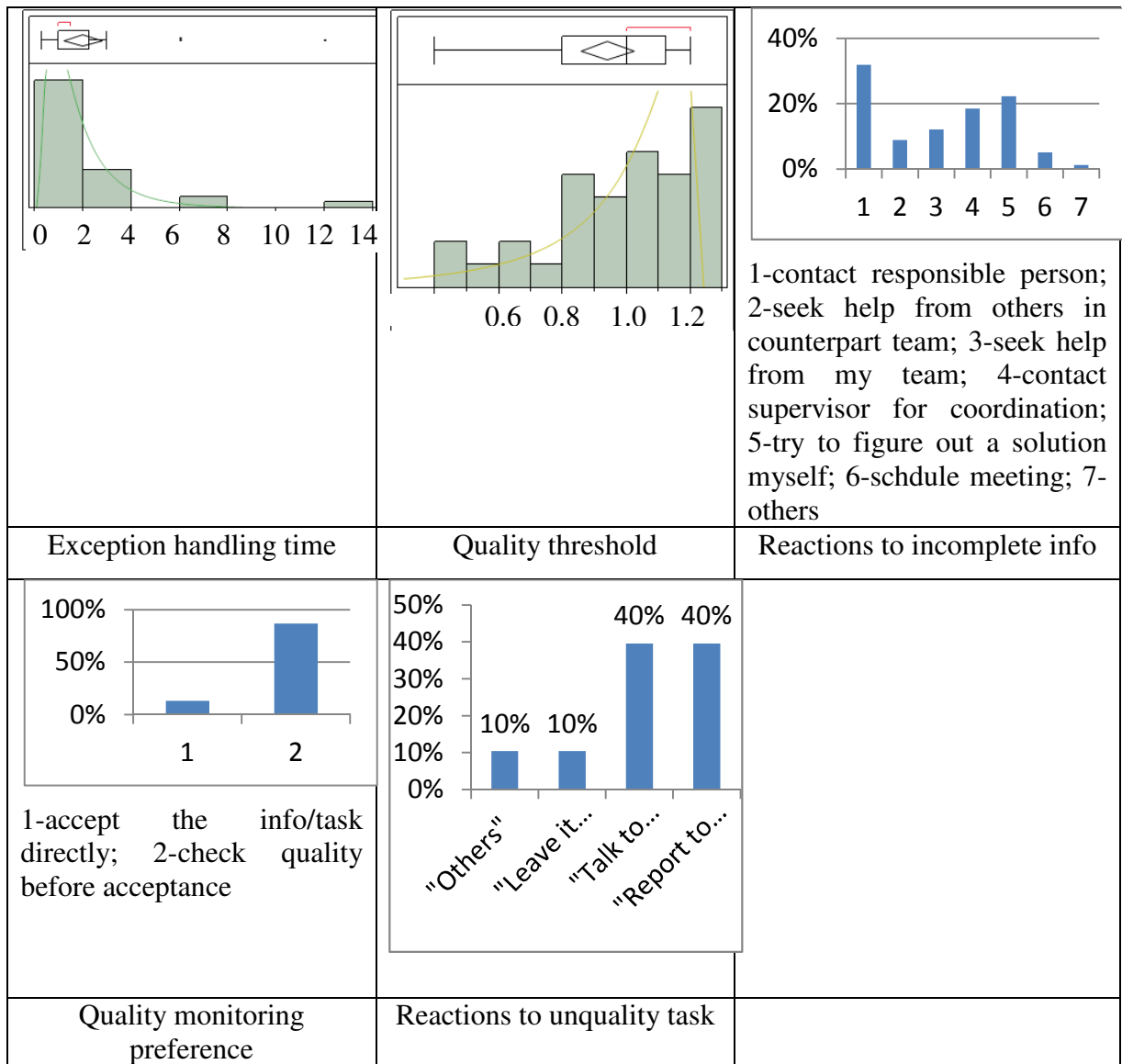
### A3.2 Model parameters

Based on data instruments, the model parameters used in case study 2 were collected. Since Monte Carlo simulation was used in case study 2, PDFs were fitted against the collected data. These PDFs were used as the inputs of the simulations. The following figures demonstrate some of the fitted PDFs.



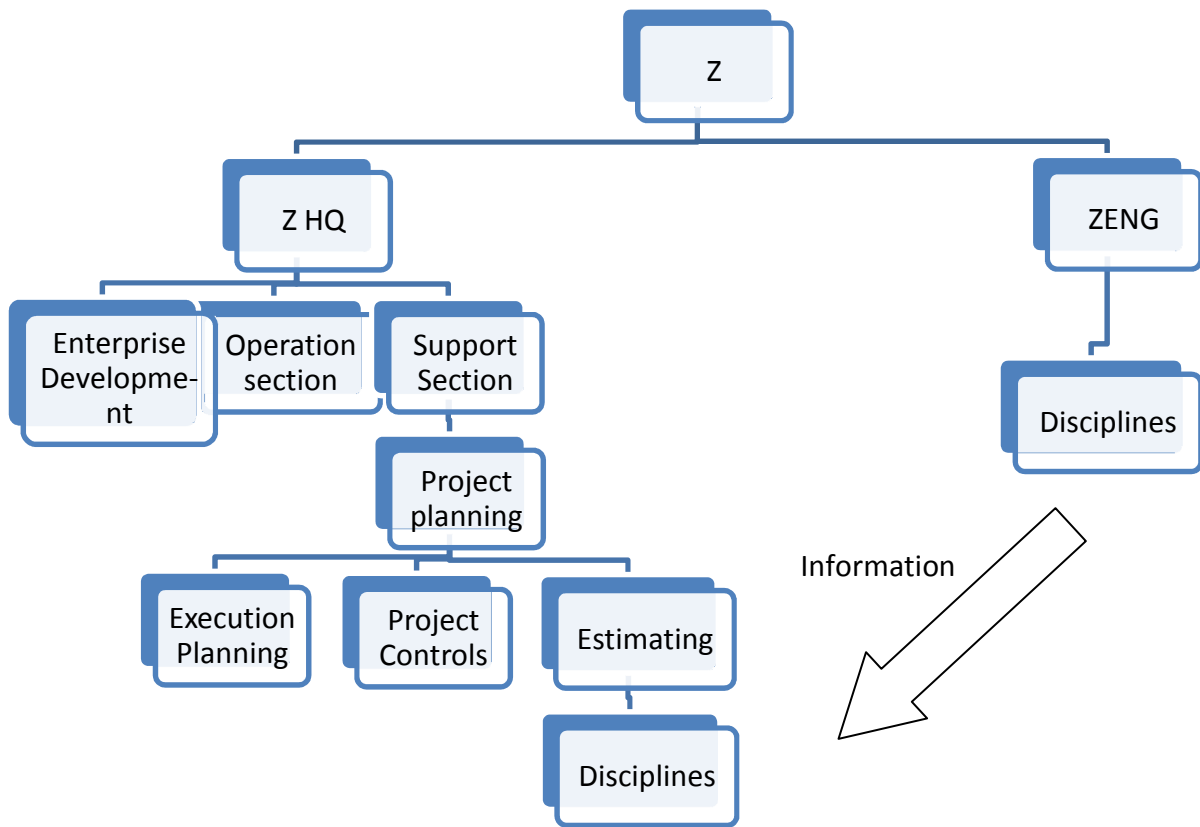
**Figure A.3** Fitted PDFs for input data

Figure A.3 Cont'd



### A3.3 Model development

The following figure shows the organizational chart of the studied company. Detailed team structure is not shown in this document.

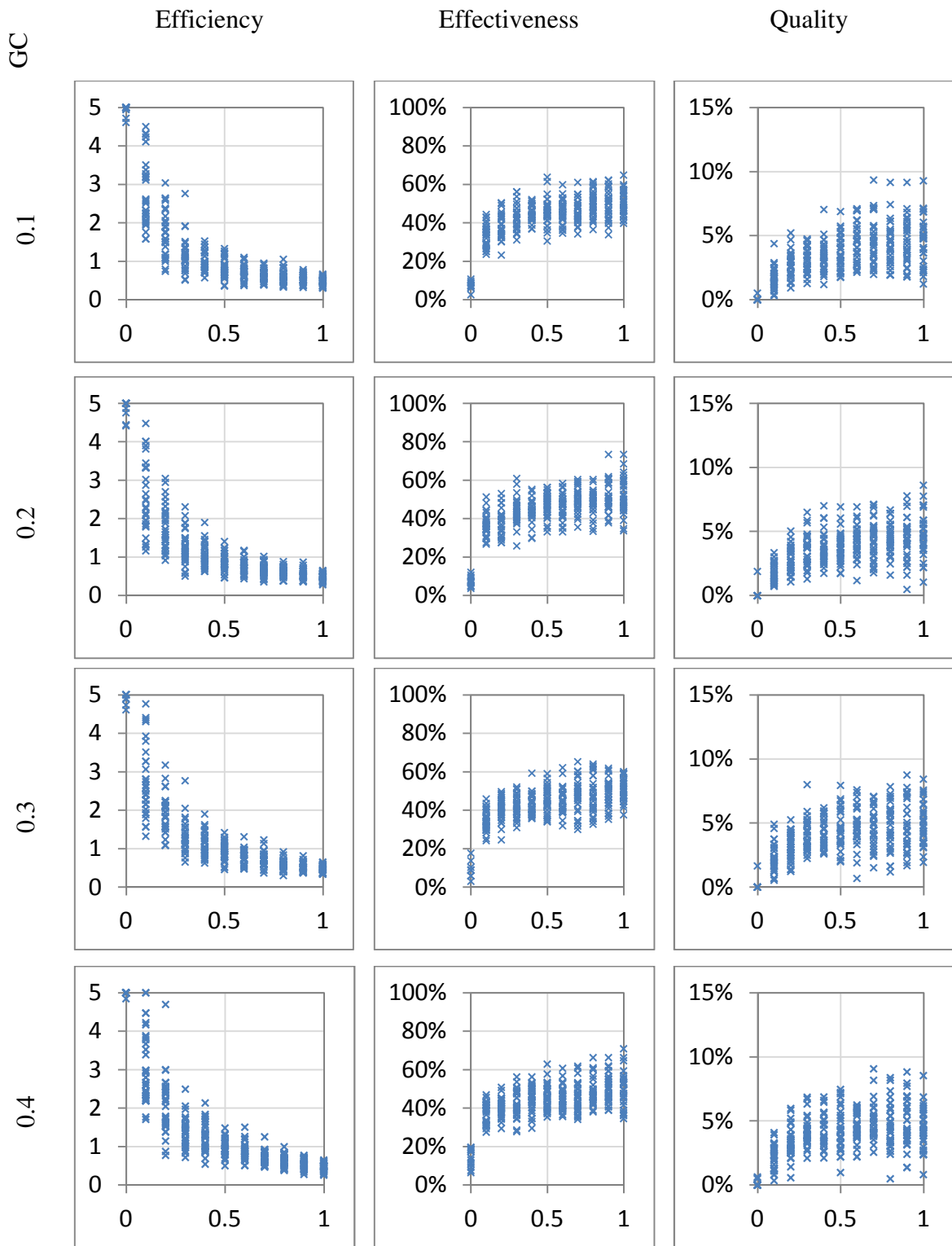


**Figure A.4** Organizational Chart of company Z

The work flow of proposal development has also been summarized (Not shown). In simulations, this flowchart was converted to the possibility of a task to be assigned to a particular actor.

### A3.4 Outputs

3300 simulations were conducted to examine the influence of task dependence and goal congruence on the performance of the project team. The following figure demonstrates the results.



**Figure A.5** Influences of task dependence and goal congruence on performance of proposal development

Figure A.5 Cont'd

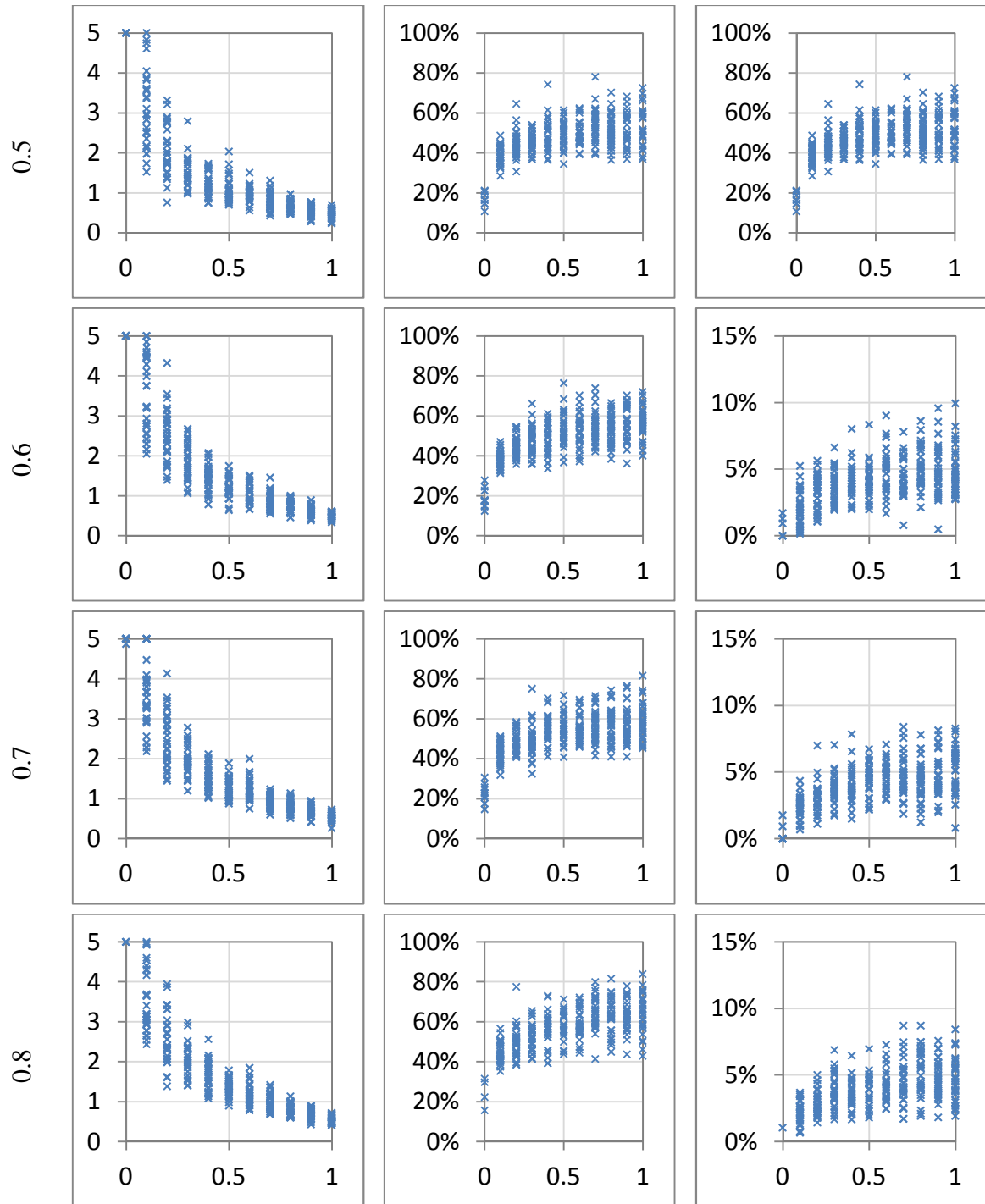
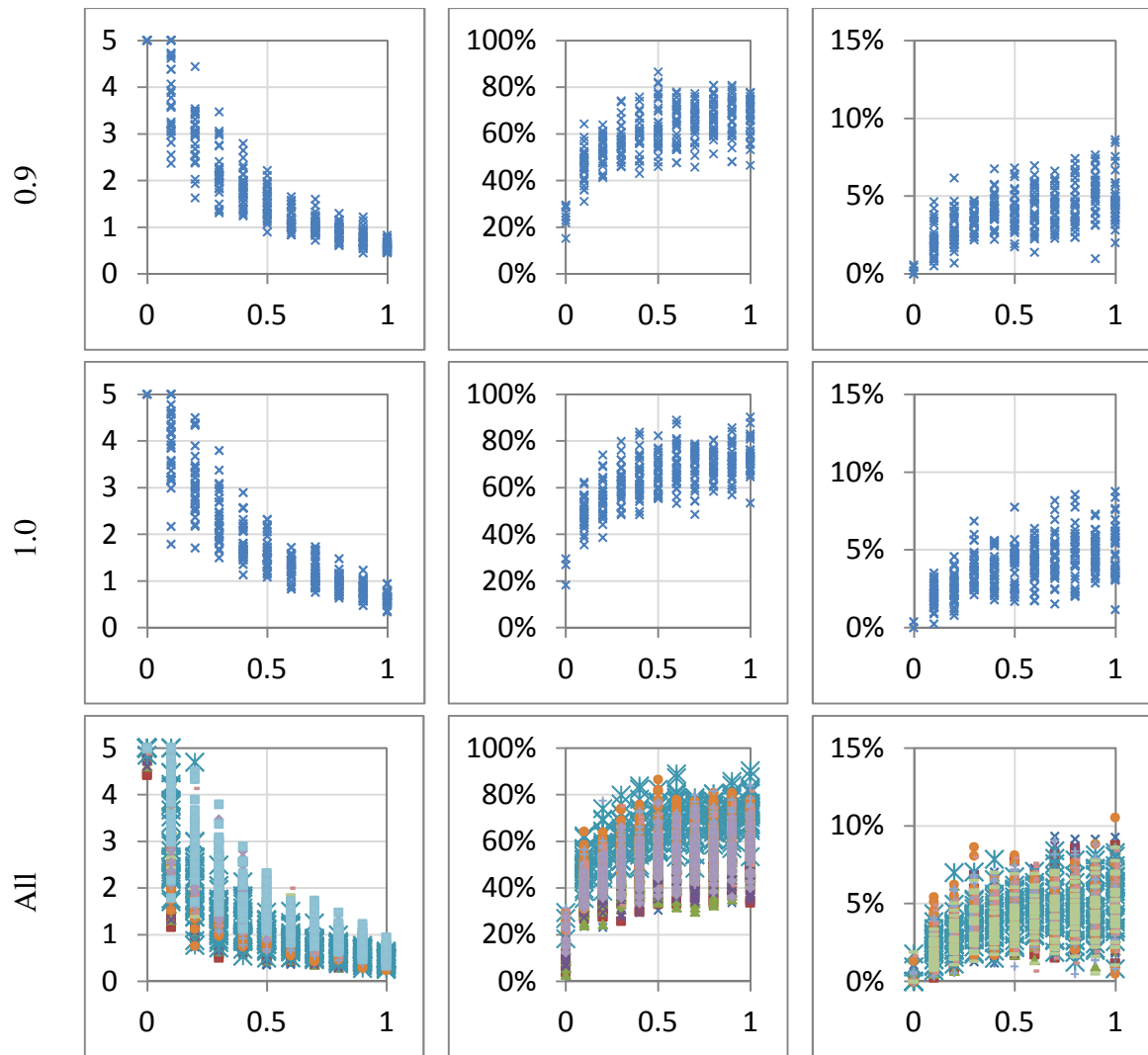
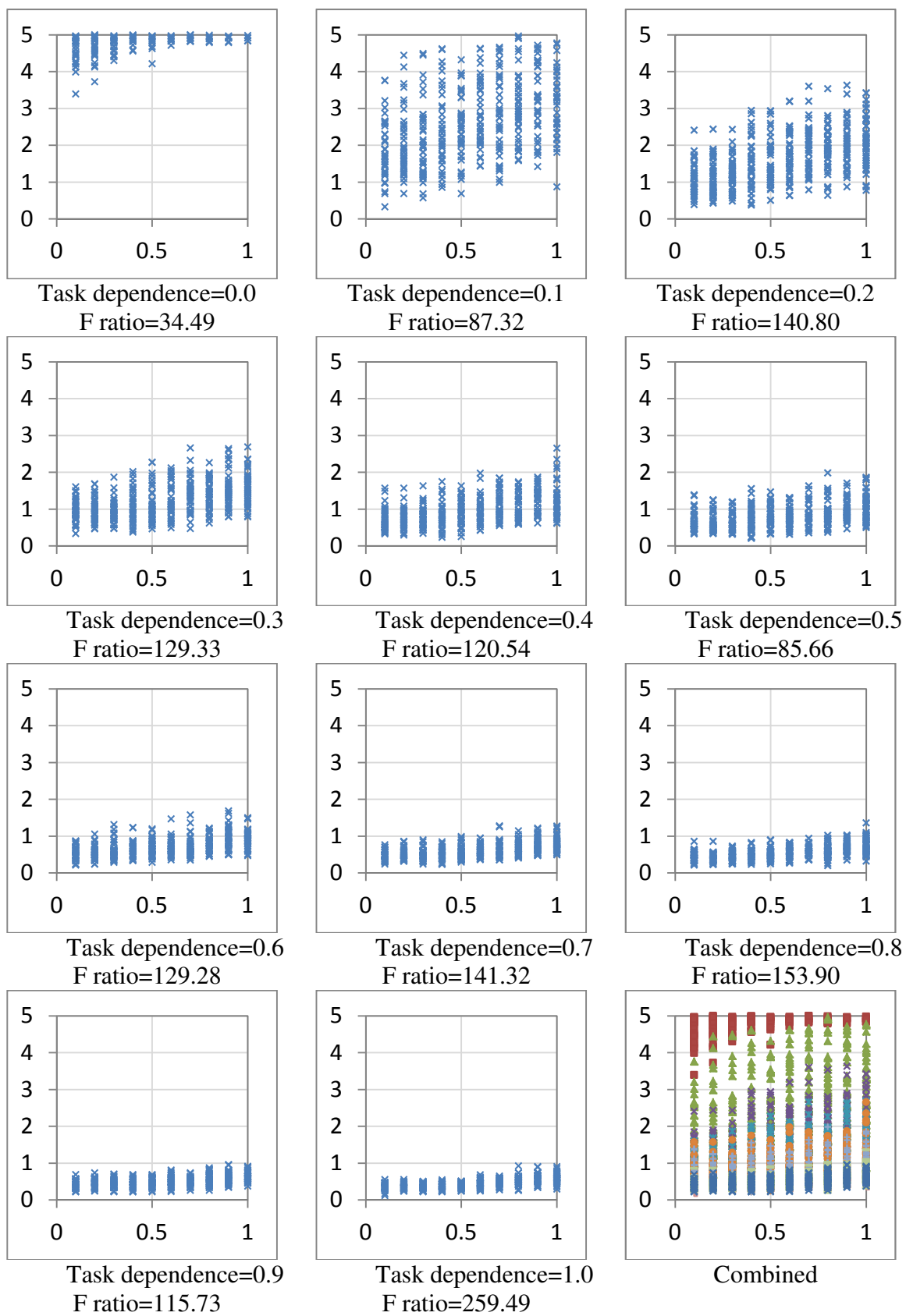




Figure A.5 Cont'd

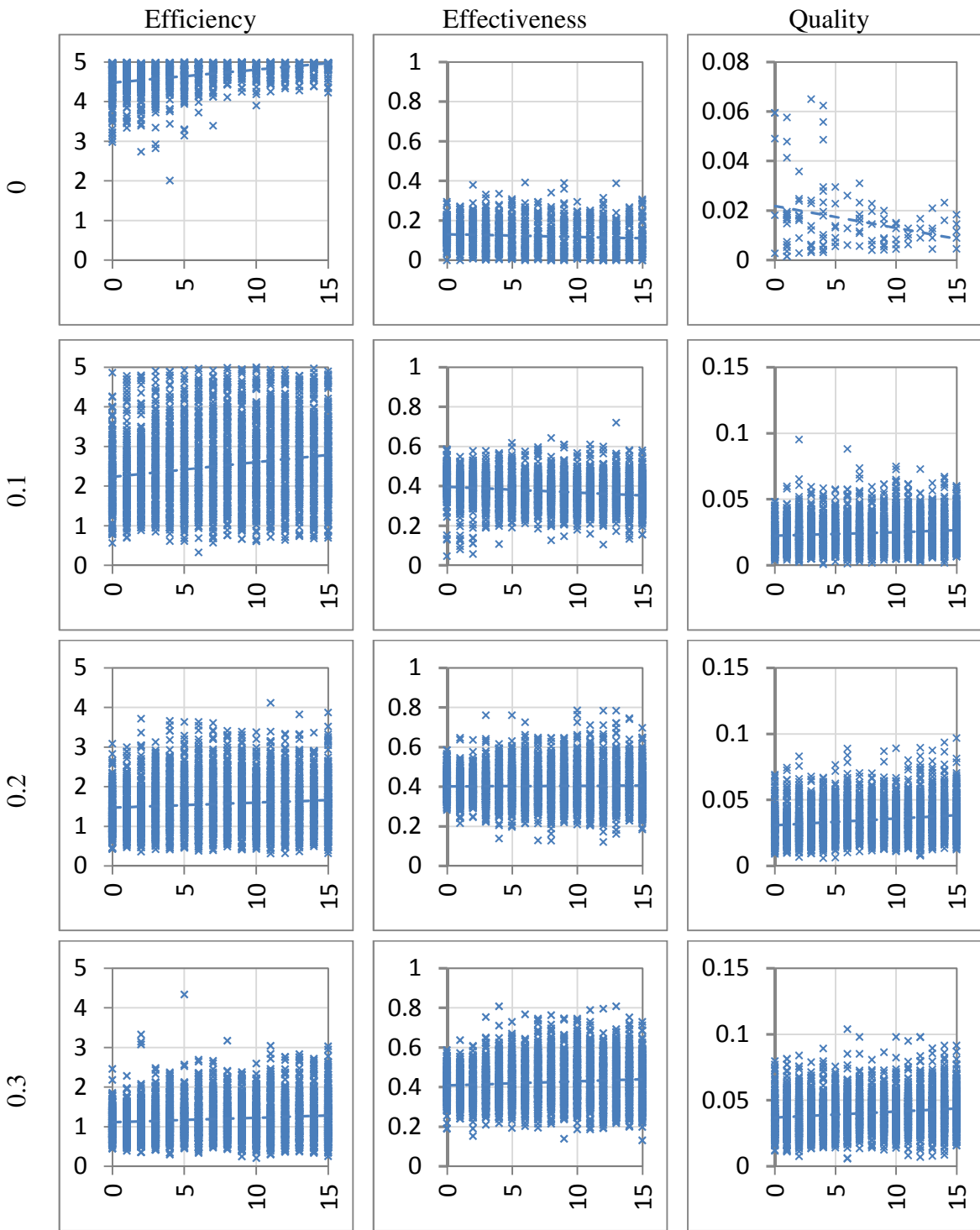


The following figures shows the change of efficiency when task dependence ranges from 0 to 1. Result shows task dependence amplifies the effects of goal congruence (F ratio is increasing).



**Figure A.6** Additional influences of task dependence on the effects of goal

The following figure shows the influence of micro-management and task dependence on team performance based on 5280 simulations.



**Figure A.7** Influences of micro-management preference on team performance under levels of task dependence

Figure A.7 Cont'd

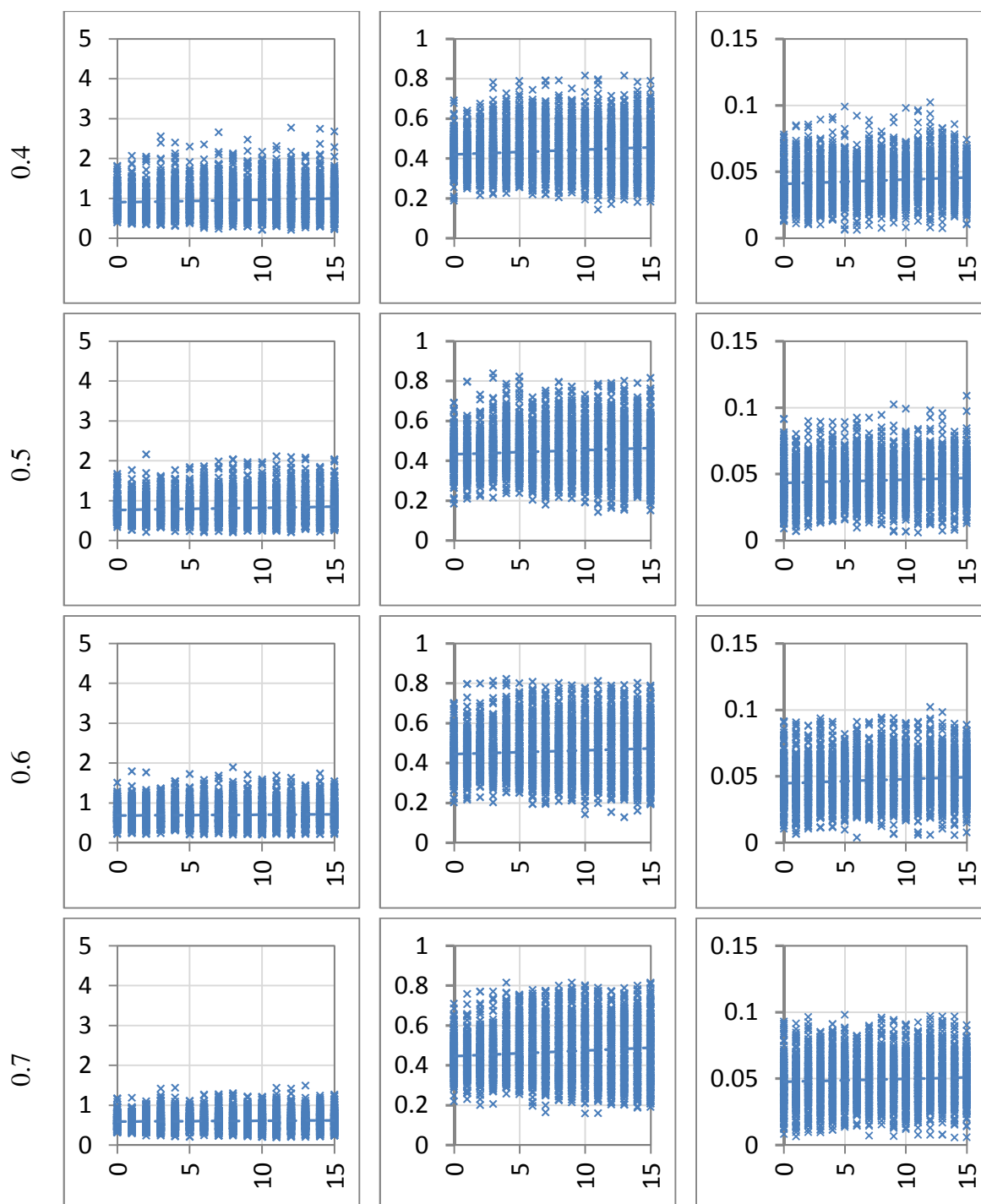
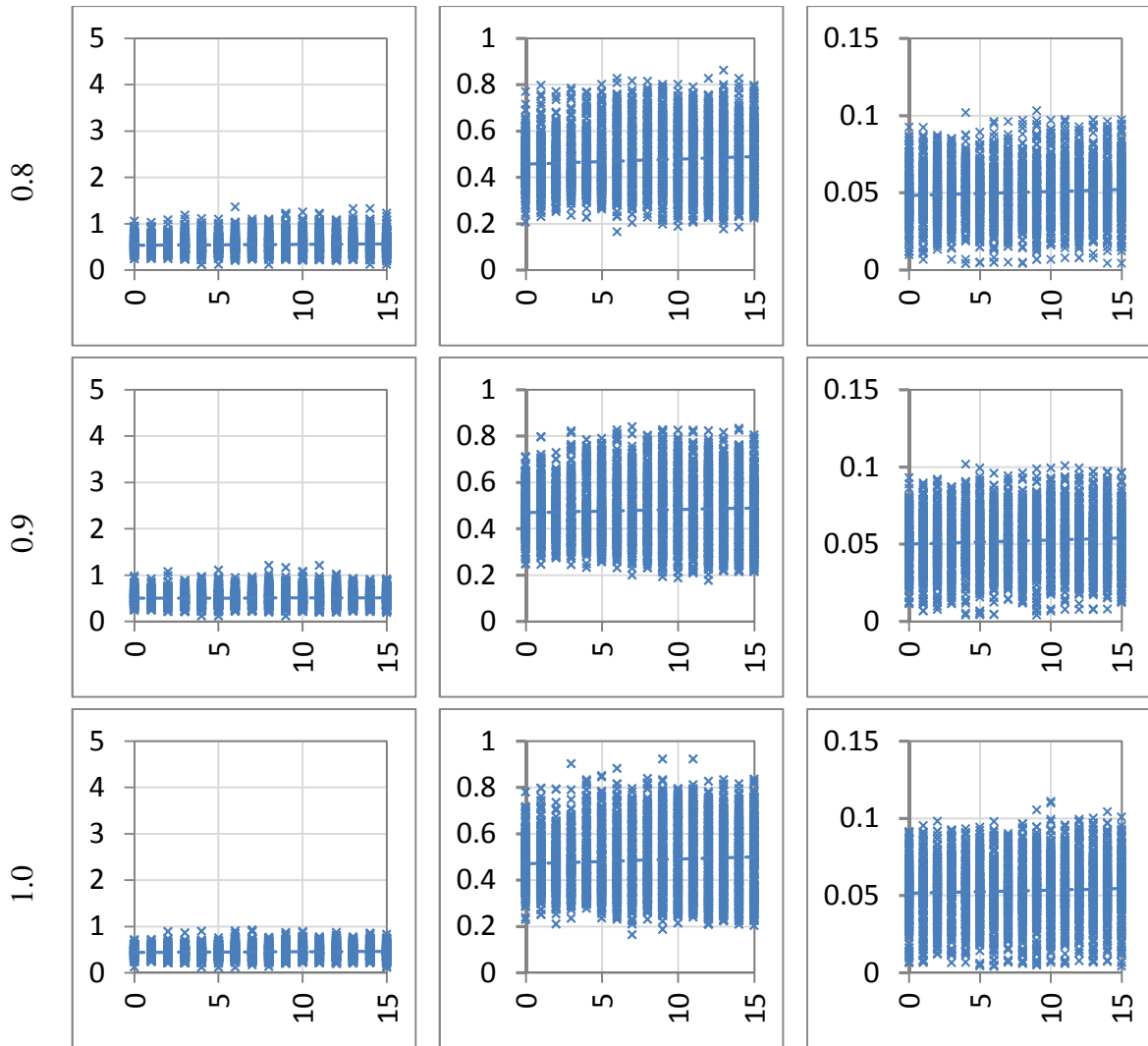
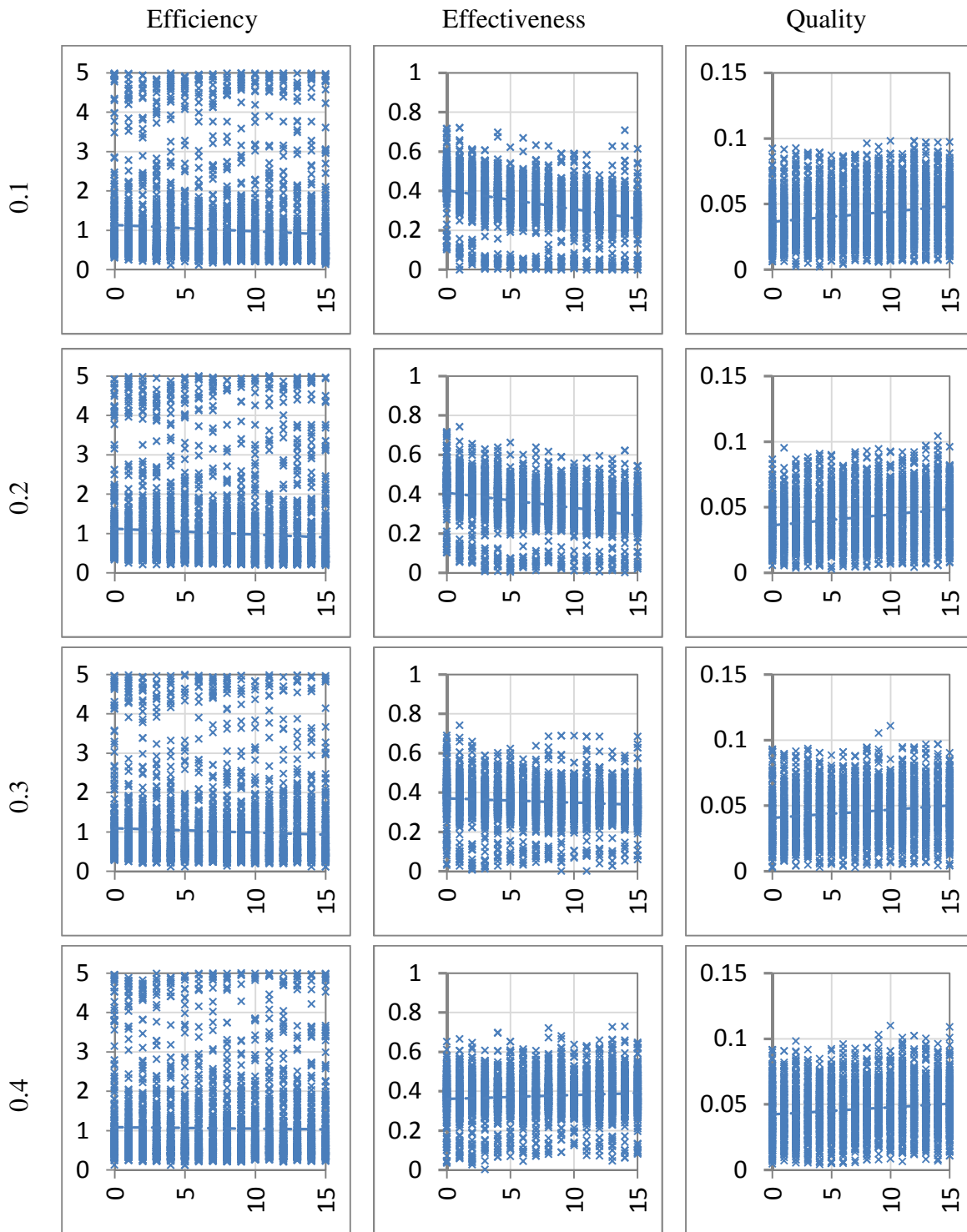


Figure A.7 Cont'd



The following figure shows the influence of goal congruence and micro-management on team performance based on 4800 simulations.



**Figure A.8** Influences of micro-management preference on team performance under levels of task dependence

Figure A.8 Cont'd

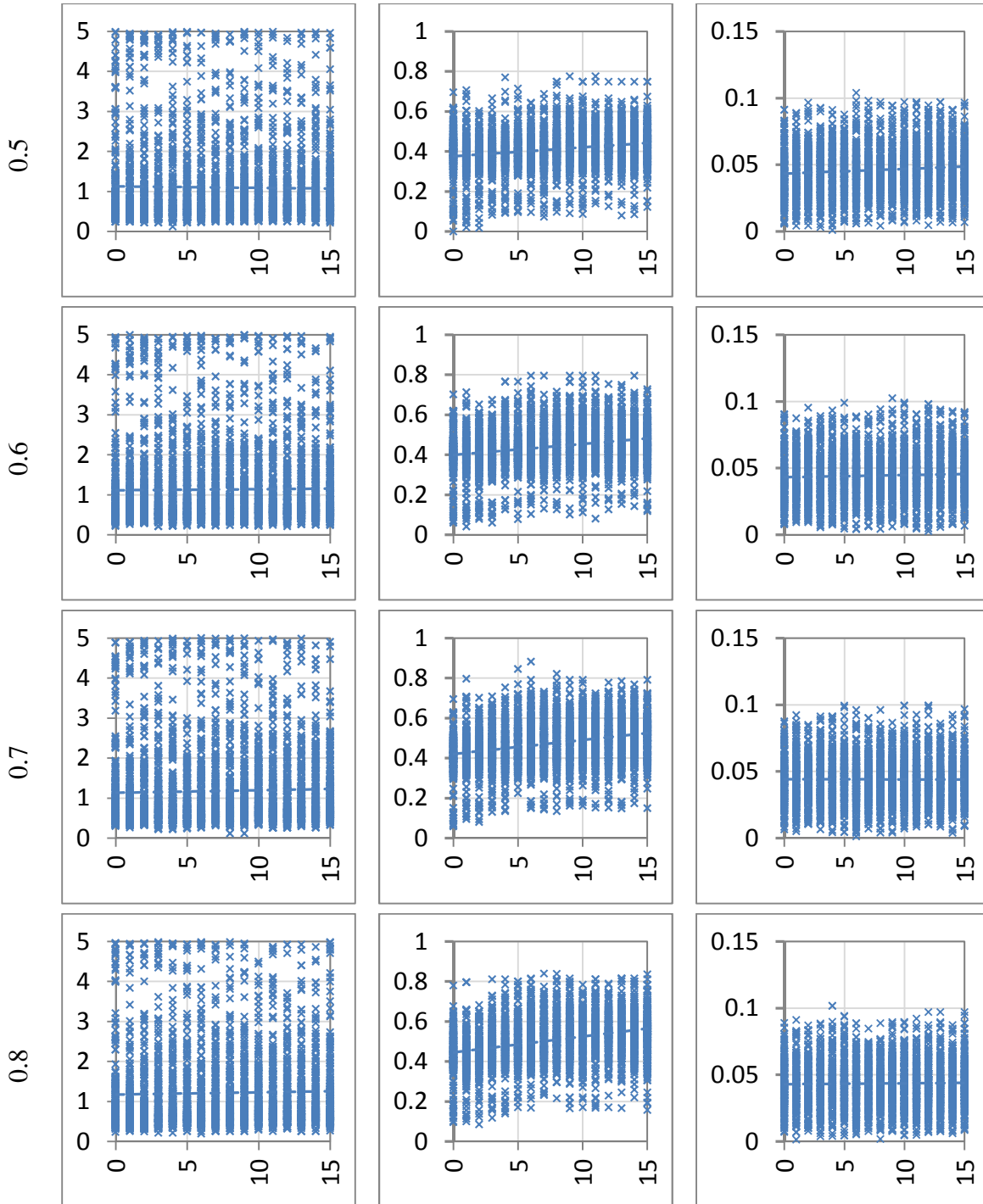
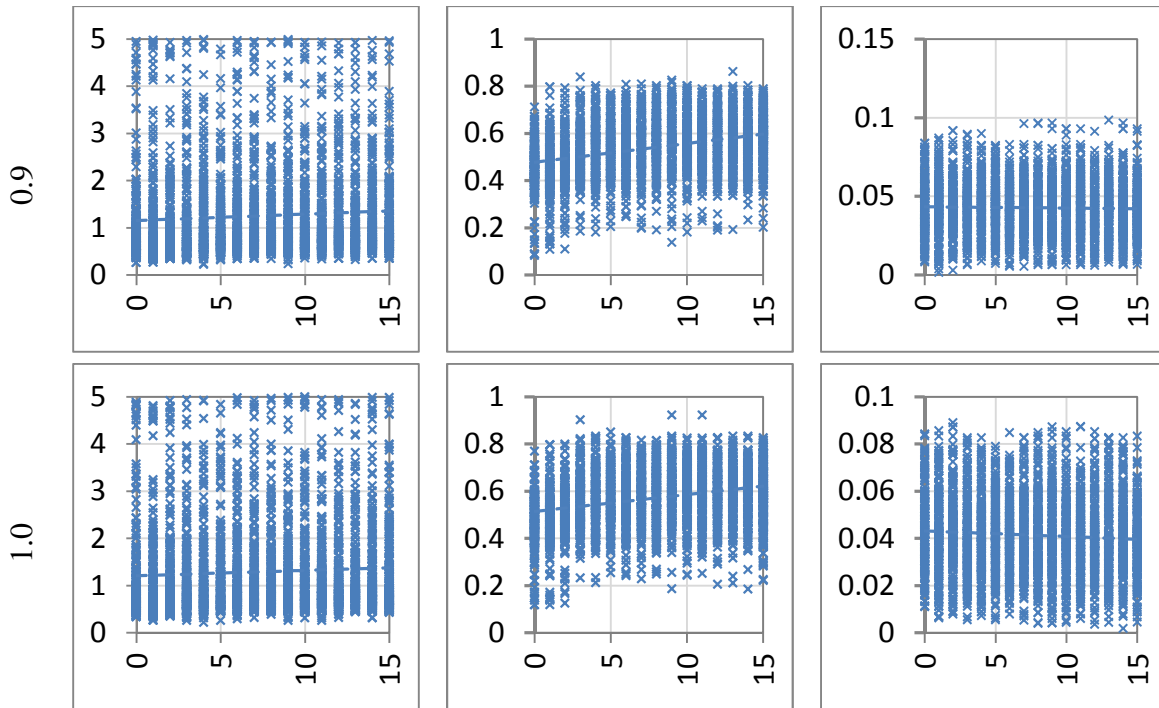


Figure A.8 Cont'd





## APPENDIX 3: SAMPLE CODES

### A3.1 Project

```
// The majority of codes of signal project scenario

public class Project {

    @Parameter (displayName = "size", usageName = "size")
    public double getSize() {
        return size
    }
    // other parameters are not shown in this document
}

public double roundnum = 0
private static final long serialVersionUID = 1L
protected static long agentIDCounter = 1
protected String agentID = "Project " +
(agentIDCounter++)
    @ScheduledMethod(
        start = 1d,
        interval = 1d,
        shuffle = true
    )
    public def generate() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        if (size>0) {
            Context context = FindContext("VOICE")
            Iterator list =
context.getObjects(Task.class).iterator()
            Projection grid =
(Grid)FindProjection("VOICE/Grid")
            int flag=1
            while (list.hasNext() && flag==1) {
                Task atask = list.next()
                setEffective(effective+atask.process)
setIneffective(ineffective+atask.routine+atask.com+atask.mee
ting)
                setErrorpercent(perror/(1000-left))

setEffectiveratio(effective/(effective+ineffective))
```

```

        if (atask.dependency==1) {
            flag=0
        } else {
        }
    }
    if (flag==0) {
    } else {
        Task task=new Task ()
        AddAgentToContext("VOICE", task)
        task.Initialize()
        Network network =
(Network)FindProjection("VOICE/Work")
        Iterator actors = new
NetworkSuccessor(network, this).query().iterator()
        Object startActor = new Object()
        while (actors.hasNext()) {
            Object actor = actors.next()
            if (actor.fit==task.fit) {
                startActor = actor
            } else {
            }
        }
        int x = grid.getLocation(startActor).getX()
        int y = grid.getLocation(startActor).getY()
        MoveAgent("VOICE/Grid", task, x, y)
        setSize(size-task.amount)
    }
    } else {
        Context context = FindContext("VOICE")
        Iterator list =
context.getObjects(Task.class).iterator()
        if (list.hasNext()) {
        } else {
            setProjecttick(GetTickCount())
            EndSimulationRun()
        }
    }
    return returnValue
}
@ScheduledMethod(
    start = 0d,
    shuffle = true

```

```

    )
    public def Initialize() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        setDependprob(GetParameter("dependprob"))
        setCongruence(GetParameter("congruence"))
        setRoundnum(GetParameter("roundnum"))
        return returnValue
    }
    @ProbeID()
    public String toString() {

        def returnValue
        def time = GetTickCountInTimeUnits()
        returnValue = this.agentID
        return returnValue
    }
}

// The majority of codes of multi-project scenario

public class Project {
    @Parameter (displayName = "Project size", usageName =
"size")
    public double getSize() {
        return size
    }
    public void setSize(double newValue) {
        size = newValue
    }
    public double size = 0

    // other parameters are not shown in this document

    private static final long serialVersionUID = 1L
    protected static long agentIDCounter = 1
    protected String agentID = "Project " +
(agentIDCounter++)
    @ScheduledMethod(
        start = 1d,
        interval = 1d,
        shuffle = true

```

```

)
public def generate() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    if (size>0) {
        Projection grid =
(Grid)FindProjection("VOICE/Grid")
        Iterator list = new GridWithin(grid, this,
40).query().iterator()
        int flag=1
        while (list.hasNext() && flag==1) {
            Object o = list.next()
            if (o instanceof Task) {
                Task otask=(Task)o
                if (otask.idnumber == idnumber) {
                    setEffective(effective+otask.process)
setIneffective(ineffective+otask.routine+otask.com+otask.mee
ting)

setEffectiveratio(effective/(effective+ineffective))
                    if (otask.dependency==1) {
                        flag=0
                    } else {
                    }
                } else {
                }
            } else {
            }
        }
        if (flag==0) {
        } else {
            double[][] AmountArray=new double[3][20]
AmountArray=[[5,5,10,15,15,10,20,20,25,10,5,5,10,15,20,15,10
,10,5,5],[5,9,10,10,15,12,20,10,25,10,10,10,10,15,10,15,10,1
0,5,10],[15,15,10,15,15,10,20,20,30,20,5,5,10,15,20,15,10,10
,5,8]]

            double[][] DifficultyArray=new double[3][20]
DifficultyArray=[[1,1,1,1.1,1.1,1.2,1.2,1.5,1.2,1,1,1,1.2,1,
0.5,1,1,1,1,1],[1.1,1,1.1,1.1,1.1,1.1,1,1.2,1.2,1.2,1,1,1,1.2,1,
0.5,1,1,1,1,1],[1,1.2,1,1.1,1.1,1.2,1.2,1.2,1.2,1,1.1,1,1,1,
0.8,1,1,1,1,1]]

            double[][] PriorityArray=new double[3][20]

```

```

PriorityArray=[ [1,1,1,1.1,1.1,1,1,1,1.2,1,1,1,1.5,1,1,2,1,2,
2,1.5], [1.1,1,1.1,1.1,1.1,1,1.2,1.2,1.2,1,1,1,1.2,1,1,1,1,2,
2,2], [1,1,1,1.2,1.1,1,1,1.2,1.1,1,1.1,1,1,1,1,1,2,1.8,2]]
    int[][] DependencyArray=new int[3][20]
DependencyArray=[ [1,1,1,1,1,0,0,0,1,1,1,0,1,0,0,0,1,1,1,1], [
1,1,0,0,1,0,0,0,1,1,1,0,1,0,0,0,1,1,1,1], [1,1,1,1,1,0,1,0,1,
1,1,0,1,0,0,0,1,1,1,1]]
    int[][] NeedinfoArray=new int[3][20]
NeedinfoArray=[ [1,1,0,0,0,1,1,1,1,0,0,0,0,0,1,1,1,0,0,0], [1,
1,0,0,0,1,1,1,1,0,0,0,0,0,1,1,1,0,0,0], [1,1,0,0,0,1,1,1,1,0,
0,0,0,0,1,1,1,0,0,0]]
    int[][] AuthorityArray=new int[3][20]
AuthorityArray=[ [1,1,1,2,2,2,1,1,1,1,1,3,3,1,1,1,1,1,2], [1
,2,2,2,2,2,1,1,1,1,1,3,3,1,1,1,1,1,2], [1,1,1,1,1,2,1,2,2,1
,1,3,3,1,1,1,1,1,1]]
    int[][] FitArray=new int[3][20]
FitArray=[ [1,1,1,2,2,2,1,1,1,1,1,3,3,1,1,1,1,1,2], [1,2,2,2
,2,2,1,3,1,3,1,3,3,1,1,1,1,1,2], [1,1,1,1,1,2,1,2,2,1,1,3,3
,1,1,1,1,3,1,1]]
    int[][] ConcurArray=new int[3][20]
ConcurArray=[ [1,2,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1], [1,1,
2,1,1,2,1,1,1,1,1,1,1,1,1,1,1,1], [1,1,1,2,1,2,1,1,1,1,1,
1,1,1,1,1,1,1,1]]
    Task task=new Task ()
    AddAgentToContext("VOICE", task)
    task.fit = FitArray[idnumber-1][taskid]
    Network network =
(Network)FindProjection("VOICE/Work")
    Iterator actors = new
NetworkSuccessor(network, this).query().iterator()
    Object startActor = new Object()
    while (actors.hasNext()) {
        Object actor = actors.next()
        if (actor.fit==task.fit) {
            startActor = actor
        } else {
        }
    }
    int x = grid.getLocation(startActor).getX()
    int y = grid.getLocation(startActor).getY()
    MoveAgent("VOICE/Grid", task, x, y)
    task.idnumber=idnumber

```

```

        task.type=type

task.difficulty=complexity*DifficultyArray[idnumber-
1][taskid]
        task.priority=urgent*PriorityArray[idnumber-
1][taskid]
        task.authority = AuthorityArray[idnumber-
1][taskid]
        task.needinfo = NeedinfoArray[idnumber-
1][taskid]
        task.dependency = DependencyArray[idnumber-
1][taskid]

        task.concur = ConcurArray[idnumber-1][taskid]
        task.amount = AmountArray[idnumber-1][taskid]
        task.left=task.amount
        if (size<task.amount) {
            task.amount=size
        } else {
        }
        setSize(size-task.amount)
        setTaskid(taskid+1)
        if (task.concur>1) {
            Task task2=new Task ()
            AddAgentToContext("VOICE", task2)
            task2.fit = FitArray[idnumber-1][taskid]
            Iterator actors2 = new
NetworkSuccessor(network, this).query().iterator()
            Object startActor2 = new Object()
            while (actors2.hasNext()) {
                Object actor2 = actors2.next()
                if (actor2.fit==task2.fit) {
                    startActor2 = actor2
                } else {
                }
            }
            int x2 =
grid.getLocation(startActor2).getX()
            int y2 =
grid.getLocation(startActor2).getY()
            MoveAgent("VOICE/Grid", task2, x2, y2)
            task2.idnumber=idnumber
            task2.type=type

```

```

task2.difficulty=complexity*DifficultyArray[idnumber-
1][taskid]

task2.priority=urgent*PriorityArray[idnumber-1][taskid]
    task2.authority =
AuthorityArray[idnumber-1][taskid]
    task2.needinfo = NeedinfoArray[idnumber-
1][taskid]

    task2.dependency =
DependencyArray[idnumber-1][taskid]
    task2.amount = AmountArray[idnumber-
1][taskid]

    task2.left=task2.amount
    if (size<task2.amount) {
        task2.amount=size
    } else {
    }
    setSize(size-task2.amount)
    setTaskid(taskid+1)
} else {
}
}
} else {
    Projection grid =
(Grid)FindProjection("VOICE/Grid")
    Iterator list = new GridWithin(grid, this,
40).query().iterator()
    int flag=1
    while (list.hasNext() && flag==1) {
        Object o = list.next()
        if (o instanceof Task) {
            Task otask=(Task)o
            setEffective(effective+otask.process)
            setIneffective(ineffective+otask.routine)

setEffectiveratio(effective/(effective+ineffective))
            if (otask.idnumber == idnumber) {
                flag=0
            } else {
            }
        } else {

```

```

        }
    }
    if (flag==0) {
    } else {
        Context context =
RemoveAgentFromContext("Grid", this)
    }
}
return returnValue
}
@ProbeID()
public String toString() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    returnValue = this.agentID
    return returnValue
}
}

```

### A3.2 Task

// The majority of codes

```

public class Task {
    @Parameter (displayName = "amount", usageName = "amount")
    public double getAmount() {
        return amount
    }
    public void setAmount(double newValue) {
        amount = newValue
    }
    public double amount = 0
}

```

// other parameters are not shown in this document

```

private static final long serialVersionUID = 1L
protected static long agentIDCounter = 1
protected String agentID = "Task " + (agentIDCounter++)
public def Initialize() {
    def returnValue
    def time = GetTickCountInTimeUnits()
}

```



```

        RandomHelper.createNormal(24, 4)

setAmount(Math.floor(0.5*RandomHelper.getNormal().nextDouble
()))
    setFit((int)Math.ceil(RandomDraw(0, 3)))
    setAuthority(RandomDraw(0, 3))
    setLeft(amount)
    setPriority(RandomDraw(0, 3))
    setDifficulty(1)
    RandomHelper.createNormal(0.3, 0.15)
    setInfo(RandomHelper.getNormal().nextDouble())
    double dependprob= GetParameter("dependprob")
    if (RandomDraw(0, 1)>dependprob) {
        setDependency(0)
    } else {
        setDependency(1)
    }
    return returnValue
}
@ProbeID()
public String toString() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    returnValue = this.agentID
    return returnValue
}
}

```

### A3.3 President/VP

// The majority of codes

```

public class Vp {
    @Parameter (displayName = "meeting", usageName =
"meeting")
    public int getMeeting() {
        return meeting
    }
    public void setMeeting(int newValue) {
        meeting = newValue
    }
}

```

```

public int meeting = 0

@Parameter (displayName = "urgentTask", usageName =
"urgentTask")
private static voice.Task getUrgentTask() {
    return urgentTask
}
private static void setUrgentTask(voice.Task newValue) {
    urgentTask = newValue
}

private static voice.Task urgentTask = new
voice.Task()

// other parameters are not shown in this document

private static final long serialVersionUID = 1L
protected static long agentIDCounter = 1
protected String agentID = "Vp " + (agentIDCounter++)
@ScheduledMethod(
    start = 1d,
    interval = 1d,
    shuffle = true
)
public def vp() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    if (meeting>0) {
        setMeeting(meeting-1)
    } else {
        Network network =
(Network)FindProjection("VOICE/Report")
        Projection grid =
(Grid)FindProjection("VOICE/Grid")
        this.meeting()
        this.prioritize()
        if (urgentTask.request==1) {
            this.approve()
        } else {
            if (urgentTask.conflict==1) {
                this.coordinate()
            } else {
            }
        }
    }
}

```

```

        }
    }
    return returnValue
}
@ScheduledMethod(
    start = 0d,
    shuffle = true
)
public def initialize() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    setExceptionthred((int)Math.floor(PDF1(a, b)))
    setProcesstime(Math.floor(PDF2(c, d)))
    setProcesstimeb(processtime)
    return returnValue
}
@ProbeID()
public String toString() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    returnValue = this.agentID
    return returnValue
}
}

```

### A3.4 Coordinator/Manager

// The majority of codes

```

public class Coordinator {
    @Parameter (displayName = "authoritythres", usageName =
"authoritythres")
    public double getAuthoritythres() {
        return authoritythres
    }
    public void setAuthoritythres(double newValue) {
        authoritythres = newValue
    }
}

```

```

    @Parameter (displayName = "urgentTask", usageName =
"urgentTask")
    private static voice.Task getUrgentTask() {
        return urgentTask
    }
    private static void setUrgentTask(voice.Task newValue) {
        urgentTask = newValue
    }
    private static voice.Task urgentTask = new
voice.Task()

// other parameters are not shown in this document

    public double authoritythres = 0
    private static final long serialVersionUID = 1L
    protected static long agentIDCounter = 1
    protected String agentID = "Coordinator " +
(agentIDCounter++)
    @ScheduledMethod(
        start = 1d,
        interval = 1d,
        shuffle = true
    )
    public def coor() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        if (meeting>0) {
            setMeeting(meeting-1)
        } else {
            Projection grid =
(Grid)FindProjection("VOICE/Grid")
            GridPoint point = grid.getLocation(this)
            setThisX(point.getX())
            setThisY(point.getY())
            this.prioritize()
            if (urgentTask.approval==0 &&
urgentTask.authority > authoritythres) {
                this.request()

            } else {
                if (urgentTask.request==1) {
                    this.approve()

```

```

        } else {
            if (urgentTask.complain==1) {
                this.reassign()
            } else {
                if (urgentTask.conflict==1) {
                    this.coordinate()
                } else {
                    if (urgentTask.report==1) {
grid.moveTo(urgentTask, urgentTask.staffX, urgentTask.staffY)
                        urgentTask.report=0

urgentTask.priority=urgentTask.priority-3
                    } else {
                        if (urgentTask.submit==1) {
                            this.monitor()
                        } else {
                            this.assign()
                        }
                    }
                }
            }
        }
    }
}

return returnValue
}

@ProbeID()
public String toString() {

    def returnValue
    def time = GetTickCountInTimeUnits()
    returnValue = this.agentID
    return returnValue
}
}

```

### A3.5 Staff

```

// The majority of codes

public class Staff {

```

```

    @Parameter (displayName = "competence", usageName =
"competence")
    public double getCompetence() {
        return competence
    }
    public void setCompetence(double newValue) {
        competence = newValue
    }
    public double competence = 0

    @Parameter (displayName = "urgentTask", usageName =
"urgentTask")
    private static voice.Task getUrgentTask() {
        return urgentTask
    }
    private static void setUrgentTask(voice.Task newValue) {
        urgentTask = newValue
    }
    private static voice.Task urgentTask = new voice.Task()
// other parameters are not shown in this document

    private static final long serialVersionUID = 1L
    protected static long agentIDCounter = 1
    protected String agentID = "Staff " + (agentIDCounter++)
    @ScheduledMethod(
        start = 1d,
        interval = 1d,
        shuffle = true
    )
    public def staff() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        if (meeting>0) {
            setMeeting(meeting-1)
        } else {

            Projection grid =
(Grid)FindProjection("VOICE/Grid")
            GridPoint point = grid.getLocation(this)
            setThisX(point.getX())
            setThisY(point.getY())
            this.prioritize()

```

```

        setAttt(atts+ttt)
        double tick = GetTickCount()
        setAveatts(atts/tick)
        if (ttt>capacity && urgentTask.must==0) {
            this.complain()
        } else {
            if (urgentTask.approval==0 &&
urgentTask.authority > authoritythres ) {
                this.request()
            } else {
                if (urgentTask.info<infothres &&
urgentTask.round <=
(int)Math.ceil(roundthres/Math.pow(10,timepressure)) &&
urgentTask.infogot==0) {
                    this.infoneed()
                } else {
                    if (urgentTask.infogot==1 &&
urgentTask.round <= (int)Math.ceil(roundthres)) {
                        this.monitor()
                    } else {
                        if
(urgentTask.round>(int)Math.ceil(roundthres)) {
                            this.report()
                        } else {
                            if (urgentTask.redo==1) {
                                this.redo()
                            } else {
                                this.process()
                            }
                        }
                    }
                }
            }
        }
    }
}
return returnValue
}

```

### A3.6 Engineer

```

// The majority of codes

public class Engineer {
    @Parameter (displayName = "meeting", usageName =
"meeting")
    public def getMeeting() {
        return meeting
    }
    public void setMeeting(def newValue) {
        meeting = newValue
    }
    public def meeting = 0

    @Parameter (displayName = "urgentTask", usageName =
"urgentTask")
    private static voice.Task getUrgentTask() {
        return urgentTask
    }
    private static void setUrgentTask(voice.Task newValue) {
        urgentTask = newValue
    }
    private static voice.Task urgentTask = new voice.Task()

// other parameters are not shown in this document

    private static final long serialVersionUID = 1L
    protected static long agentIDCounter = 1
    protected String agentID = "Engineer " +
(agentIDCounter++)
    public def infofeed() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        Projection grid = (Grid)FindProjection("VOICE/Grid")
        urgentTask.com=1
        urgentTask.process=0
        urgentTask.routine=0
        urgentTask.meeting=0
        if (infotime>0) {
            setInfotime(infotime-1)
        } else {
            urgentTask.info=urgentTask.info+(1-
urgentTask.info)*info

```



```

        urgentTask.infogot=1
        urgentTask.engX=thisX
        urgentTask.engY=thisY
        grid.moveTo(urgentTask, urgentTask.staffX,
urgentTask.staffY)
        setInfotime(infotimeb)
    }
    return returnValue
}
@ProbeID()
public String toString() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    returnValue = this.agentID
    return returnValue
}
}

```

### A3.7 Behaviors

#### Prioritizing

```

public def prioritize() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    setTtt(0)
    setUrgentTask(new Task())
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    Iterator list = new GridWithin(grid, this,
0).query().iterator()
    while (list.hasNext()) {
        Task task = list.next()
        setTtt(ttt+task.left*task.difficulty/competence)
        if (task.priority >= urgentTask.priority) {
            setUrgentTask(task)
        } else {
        }
    }
    if (urgentTask.amount>0) {
    } else {

```

```

    }
    return returnValue
}

```

### Processing/Submission

```

public def process() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    if (urgentTask.left <= 0) {
        urgentTask.terror=urgentTask.terror+processerror
        urgentTask.staffX=thisX
        urgentTask.staffY=thisY
        grid.moveTo(urgentTask, upperX, upperY)
        urgentTask.submit=1
        urgentTask.left=urgentTask.amount

    } else {
        setFsa(fsa+competence)
        setFaa(faa+competence/urgentTask.difficulty)
        urgentTask.left=urgentTask.left-
competence/urgentTask.difficulty
        urgentTask.process=1
        urgentTask.routine=0
        urgentTask.com=0
        urgentTask.meeting=0
    }
    return returnValue
}

```

### Assigning

```

public def assign() {
    def returnValue

```

```

    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    Network network =
(Network)FindProjection("VOICE/Report")
    urgentTask.routine=1
    if (mgrpreference==1) {
        Iterator lowers = new NetworkPredecessor(network,
this).query().iterator()
        Staff bestLower = new Staff()
        while (lowers.hasNext()) {
            Staff lower = lowers.next()
            if (lower.competence >= bestLower.competence)
{
                bestLower = lower
            } else {
            }
        }
        int loX = grid.getLocation(bestLower).getX()
        int loY = grid.getLocation(bestLower).getY()
        grid.moveTo(urgentTask, loX, loY);
    } else {
        if (mgrpreference==2) {
            Iterator lowers = new
NetworkPredecessor(network, this).query().iterator()
            Staff bestLower = new Staff()
            while (lowers.hasNext()) {
                Staff lower = lowers.next()
                if (lower.processerror <
bestLower.processerror) {
                    bestLower = lower
                } else {
                }
            }
            int loX = grid.getLocation(bestLower).getX()
            int loY = grid.getLocation(bestLower).getY()
            grid.moveTo(urgentTask, loX, loY);
        } else {
            Iterator lowers = new
NetworkPredecessor(network, this).query().iterator()
            Staff bestLower = new Staff()
            while (lowers.hasNext()) {
                Staff lower = lowers.next()

```

```

        if (lower.ttt < bestLower.ttt) {
            bestLower = lower
        } else {
        }
    }
    int loX = grid.getLocation(bestLower).getX()
    int loY = grid.getLocation(bestLower).getY()
    grid.moveTo(urgentTask, loX, loY);
}
}
return returnValue
}

```

### Requesting

```

public def request() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    urgentTask.staffX=thisX
    urgentTask.staffY=thisY
    grid.moveTo(urgentTask, upperX, upperY);
    urgentTask.request=1
    urgentTask.priority=urgentTask.priority+3
    urgentTask.routine=1
    urgentTask.process=0
    urgentTask.com=0
    urgentTask.meeting=1
    return returnValue
}

```

### Approving

```

public def monitor() {
    def returnValue

```

```

def time = GetTickCountInTimeUnits()
urgentTask.process=1
urgentTask.routine=0
urgentTask.com=0
urgentTask.meeting=0
if (processtime<=0) {
    setProcesstime(processtimeb)
    if
(urgentTask.terror<mgrerrororthred*Math.pow(10,timepressure))
{
    Context context = FindContext("VOICE")
    Iterator list =
context.getObjects(Project.class).iterator()
    Project prjt = list.next()
    prjt.left=prjt.left-urgentTask.amount

prjt.perror=prjt.perror+urgentTask.terror*urgentTask.amount
    Context context2 =
RemoveAgentFromContext("VOICE", urgentTask)
    } else {
        Projection grid =
(Grid)FindProjection("VOICE/Grid")
        grid.moveTo(urgentTask, urgentTask.staffX,
urgentTask.staffY);
        urgentTask.redo=1
        urgentTask.priority=urgentTask.priority+3
        setException(exception+1)
    }
} else {
    setProcesstime(processtime-1)
}
return returnValue
}

```

### Information exchange

```

public def infoneed() {
    def returnValue
    def time = GetTickCountInTimeUnits()

```

```

        Projection grid = (Grid)FindProjection("VOICE/Grid")
        Network infonetwork =
(Network)FindProjection("VOICE/Info")
        Iterator infosources = new
NetworkPredecessor(infonetwork, this).query().iterator()
        Engineer bestInfosource=new Engineer()
        while (infosources.hasNext()) {
            Engineer infosource = infosources.next()
            bestInfosource = infosource
        }
        Iterator infojudge = new
NetworkPredecessor(infonetwork, this).query().iterator()
        if (infojudge.hasNext()) {
            int infoX =
grid.getLocation(bestInfosource).getX()
            int infoY =
grid.getLocation(bestInfosource).getY()
            urgentTask.staffX=thisX
            urgentTask.staffY=thisY
            urgentTask.priority=urgentTask.priority+1
            urgentTask.round=urgentTask.round+1
            grid.moveTo(urgentTask, infoX, infoY);
        } else {
            urgentTask.info=infothres
            urgentTask.terror=urgentTask.terror+0.01
            urgentTask.amount=urgentTask.amount+2
        }
        return returnValue
    }
    public def infofeed() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        Projection grid = (Grid)FindProjection("VOICE/Grid")
        urgentTask.com=1
        urgentTask.process=0
        urgentTask.routine=0
        urgentTask.meeting=0
        if (infotime>0) {
            setInfotime(infotime-1)
        } else {
            urgentTask.info=urgentTask.info+(1-
urgentTask.info)*info

```

```

        urgentTask.infogot=1
        urgentTask.engX=thisX
        urgentTask.engY=thisY
        grid.moveTo(urgentTask, urgentTask.staffX,
urgentTask.staffY)
        setInfotime(infotimeb)
    }
    return returnValue
}

```

## Meeting

```

    public def meeting() {
        def returnValue
        def time = GetTickCountInTimeUnits()
        Network network =
(Network)FindProjection("VOICE/Report")
        Projection grid = (Grid)FindProjection("VOICE/Grid")
        Iterator lowers = new NetworkPredecessor(network,
this).query().iterator()
        while (lowers.hasNext()) {
            Coordinator coor= lowers.next()
            setException(exception+coor.exception)
        }
        if (exception>exceptionthred) {

setMeeting((int)Math.ceil(5*exception/exceptionthred))
            setException(0)
            Iterator objs = new GridWithin(grid, this,
40).query().iterator()
            while (objs.hasNext()) {
                Object o = objs.next()
                if (o instanceof Staff) {
                    Staff staff=(Staff)o
                    staff.meeting=meeting+1
                } else {
                    if (o instanceof Coordinator) {

```

```

        Coordinator coor=(Coordinator)o
        coor.meeting=meeting+1
        coor.exception=0
    } else {
        if (o instanceof Engineer) {
            Engineer eng=(Engineer)o
            eng.meeting=meeting+1
        } else {
            if (o instanceof Task) {
                Task task=(Task)o
                task.approval=1
                task.terror=task.terror*0.1
                task.info=task.info*1.5

task.difficulty=task.difficulty*0.9
            } else {
            }
        }
    }
}
}
} else {
}
return returnValue
}

```

## Monitoring

```

public def monitor() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    urgentTask.process=1
    urgentTask.routine=0
    urgentTask.com=0
    urgentTask.meeting=0
    if (processtime<=0) {
        setProcesstime(processtimeb)
    }
}

```



```

        if
(urgentTask.terror<mgrerrorthred*Math.pow(10,timepressure))
{
            Context context = FindContext("VOICE")
            Iterator list =
context.getObjects(Project.class).iterator()
            Project prjt = list.next()
            prjt.left=prjt.left-urgentTask.amount

prjt.perror=prjt.perror+urgentTask.terror*urgentTask.amount
            Context context2 =
RemoveAgentFromContext("VOICE", urgentTask)
        } else {
            Projection grid =
(Grid)FindProjection("VOICE/Grid")
            grid.moveTo(urgentTask, urgentTask.staffX,
urgentTask.staffY);
            urgentTask.redo=1
            urgentTask.priority=urgentTask.priority+3
            setException(exception+1)
        }
    } else {
        setProcesstime(processtime-1)
    }
    return returnValue
}

```

Correction/rework

```

public def reassign() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    Network network =
(Network)FindProjection("VOICE/Report")
    urgentTask.routine=1
    urgentTask.process=0
    urgentTask.com=0
}

```

```

        setException(exception+1)
        urgentTask.meeting=0
        if (processtime<=0) {
            Iterator lowers = new NetworkPredecessor(network,
this).query().iterator()
            Staff bestLower = new Staff()
            bestLower.ttt=10000
            setProcesstime(processtimeb)
            while (lowers.hasNext()) {
                Staff lower = lowers.next()
                if (lower.ttt <= bestLower.ttt) {
                    bestLower = lower
                } else {
                }
            }
            int loX = grid.getLocation(bestLower).getX()
            int loY = grid.getLocation(bestLower).getY()
            urgentTask.must=1
            urgentTask.coorX=thisX
            urgentTask.coorY=thisY
            urgentTask.complain=0
            grid.moveTo(urgentTask, loX, loY);
        } else {
            setProcesstime(processtime-1)
        }
        return returnValue
    }

```

```

public def redo() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    urgentTask.submit=0
    if (urgentTask.left <= 0) {
        urgentTask.terror=urgentTask.terror*0.85
        urgentTask.staffX=thisX
        urgentTask.staffY=thisY
        grid.moveTo(urgentTask, upperX, upperY)
        urgentTask.submit=1
        urgentTask.left=urgentTask.amount
        urbanTask.redo=0
    } else {
    }
}

```

```

        setFsa(fsa+competence)
        setFaa(faa+competence/urgentTask.difficulty)
        urgentTask.left=urgentTask.left-
competence/urgentTask.difficulty
        urgentTask.process=1
        urgentTask.routine=0
        urgentTask.com=0
    }
    return returnValue
}

```

## Overburden

```

public def complain() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    urgentTask.staffX=thisX
    urgentTask.staffY=thisY
    grid.moveTo(urgentTask, upperX, upperY);
    urgentTask.complain=1
    return returnValue
}

```

## Conflict management

```

public def report() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    urgentTask.staffX=thisX
    urgentTask.staffY=thisY
    grid.moveTo(urgentTask, upperX, upperY);
    urgentTask.conflict=1
}

```

```

    urgentTask.priority=urgentTask.priority+3
    urgentTask.routine=1
    urgentTask.round=0
    return returnValue
}
public def coordinate() {
    def returnValue
    def time = GetTickCountInTimeUnits()
    Projection grid = (Grid)FindProjection("VOICE/Grid")
    urgentTask.process=0
    urgentTask.routine=1
    urgentTask.com=0
    urgentTask.meeting=0
    if (processtime<=0) {
        setProcesstime(processtimeb)
        double coordination= RandomDraw(0, 10)
        if (coordination>=coorthres) {
            grid.moveTo(urgentTask, urgentTask.staffX,
urgentTask.staffY);
            urgentTask.conflict=0
            urgentTask.info=urgentTask.info+(1-
urgentTask.info)*congruence
            urgentTask.priority=urgentTask.priority-3
        } else {
            urgentTask.coorX=thisX
            urgentTask.coorY=thisY
            grid.moveTo(urgentTask, upperX, upperY);
            setException(exception+1)
            urgentTask.routine=1
        }
    } else {
        setProcesstime(processtime-0.2)
    }
    return returnValue
}

```

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## REFERENCES

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