Global Dimension of Robust Project Network Design

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Abstract: Managing the increased complexity, emerging uncertainties, and diversity of cultures on global projects is creating significant challenges for architecture, engineering, and construction firms. In global projects, differences in "institutions"—including language, beliefs, values, group norms, work practices, professional roles, industry organizations, and legal frameworks—among team members from different national backgrounds can lead to misunderstanding and conflicts that cause delays, increase costs, and reduce quality. Previous research has examined risk factors associated with international project execution. However, little research to date has explored whether reconfiguring project networks might mitigate such risks. Project organizational simulation tools have been combined with "robust design" experimental techniques to design robust project networks that can perform reliably in uncertain conditions. This paper extends project network design research to examine whether robust designs for given project networks differ between "domestic" and "global" projects, given differing organizational uncertainties. The results demonstrate that robust project network designs may differ for global project networks. This finding has significant implications for the design of project networks in an industry where firm participation in global project networks is increasing, both domestically and abroad.

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Introduction

Managing the increased complexity, emerging uncertainties, and diversity of cultures on global projects is creating significant challenges for design and construction firms. In recent years, globalization has had a tremendous impact on the architecture, engineering, and construction (AEC) industry. More and more contractors are looking outside their home country markets for potential projects, especially with the increase in construction activities in developing countries. Engineering News Record (ENR)'s top 225 international contractors performed $224.43 billion of work outside of their home country in 2006, an increase of 18.5% over the previous year (Reina and Tulacz 2007). Companies no longer restrict themselves to pursuing projects within their home markets. Even firms that elect to compete only in domestic markets are finding themselves competing with and participating in project networks with international firms so both domestically and internationally operating AEC firms are increasingly involved in global projects.

Many researchers who study global business or global projects have used the five national value indices of Hofstede (1980, 2001) to measure the extent of "cultural differences" in a "cross-cultural" organization, with widely varying results, as several metastudies have shown (Barkema et al. 1997; Beamish and Kachra 2004; Park and Ungson 1997). Research by Horii et al. (2005), Mahalingam and Levitt (2007), and Orr and Scott (2008) found that the kinds of critical differences among team members from different national backgrounds that cause misunderstanding and conflicts on global projects—with attendant increases in schedule, cost, and quality risks—extend far beyond Hofstede's cross-cultural differences in national values such as "collectivism versus individualism." Thus, a more useful distinction would be to use the broader concept of institutions by Scott (2007) to distinguish between "monoinstitutional" versus "cross-institutional" project networks. To enhance readability, we will use the terms "domestic" versus "global" to connote the more precise terms, monoinstitutional versus cross-institutional to categorize project networks for the remainder of this paper.

Uncertainties are commonplace in construction and can have enormous impacts on costs and schedules. Some researchers describe uncertainty as a principal factor impacting project performance (Ben-Haim and Laufer 1998). Firms that fail to minimize these uncertainties will have more difficulty competing in a market where competitive pressures are increasing due to globalization. Project organizational simulation software has recently been integrated with robust design experimental methods to address these uncertainties, to design project networks that perform more predictably in dynamically uncertain project environments (Ortiz de Orue et al. 2009). However, investigations into the ro-

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bust design of project networks have focused solely on domestic projects.

Uncertainties that arise in global projects, whether constructed domestically or abroad, may affect the design of the most robust project network. Hence, the framework by Ortiz de Orue et al. (2009) may not generalize from domestic projects to global projects, where networks involve participants from multiple countries. Language barriers are certainly a problem. However, broader institutional differences among global project network participants may create new organizational uncertainties and exacerbate existing uncertainties. This paper will seek to examine whether and how the outcome of a robust project network design varies between global versus domestic project networks executing similar project tasks.

Background

Issues on Global Projects

Research over the past two decades on global design and construction projects has predominantly focused on understanding the risks involved with working on projects abroad. William and Ashley (1987) examined political risks associated with working abroad. Hastak and Shaked (2000) later developed a tool to quantify and assess risks on international projects identifying 73 risk indicators. The international risk assessment literature then expanded to quantify appropriate contingencies required to address risks on international projects (Kim et al. 2008; Sonmez et al. 2007). Researchers refined the understanding of these contingencies by developing scale-based prediction models for international project performance (Han et al. 2007a). This research was then further refined to examine the specific causes of poor profitability on international design and construction projects. Han et al. (2007a) found that the second leading cause of poor profitability on international projects was poor project planning and management. This complements the earlier finding by Gunhan and Arditi (2005) that one of the critical strengths required for success on international design and construction projects was the capability of the project manager. A significant amount of research has examined and modeled risk on international projects; however, extant research has not yet addressed how organizational design theory and methods can improve international project planning and enhance the capabilities of project managers, both of which have been found to be so critical to successful international project execution.

Organizational Issues on Global Projects

There is a growing body of research on organizational issues in the area of globalization of the AEC industry. Researchers have focused their efforts on cultural differences (Chan and Tse 2003; Horii et al. 2005; Nayak and Taylor 2009), differing institutional norms (Mahalingam and Levitt 2007), and cross-cultural communication issues (English 2002; Nayak and Taylor 2009). These problems also occur on domestic projects, but they are exacerbated when firms working together in global projects clash due to institutional differences. In the following paragraphs we will review several papers that detail specific organizational issues that impact effective international project planning and the capabilities of project managers to execute such projects.

Horii et al. (2005) examined how different organization styles coupled with different microlevel employee behavior patterns affect productivity. Specifically, American and Japanese cultures were examined in a combined case study and project organization simulation research effort. American organizations tend to have informal structures, where their employees have a pattern of individual decision making. Japanese organizations were found to have more formalized organizational structures and their employees prefer consensual decision making. Horii and colleagues modeled different combinations of U.S. versus Japanese practices (structures) and values (behaviors) to simulate the practices and values of joint ventures among companies from different countries. They assumed that the joint venture "sponsor," or leader, for each project would implement its preferred national organization style on a joint venture project. The results of their simulation showed that the Japanese organization style was the best fit for complex projects, but the American style was best for projects of medium complexity. The best employee behavioral style was the one that matched the organizational style implemented, i.e., Japanese microlevel behavior pattern worked best with the Japanese organization style. If an American organization style had employees that exhibited Japanese behaviors, or vice versa, project performance would suffer. Horii and colleagues demonstrated that cultural differences among organizational structures and behavior patterns could negatively impact project performance.

Mahalingam and Levitt (2007) studied four heavy civil infrastructure projects in India and Taiwan to understand institutional differences in safety practices. All four of them had international contractors from industrialized countries that formed joint ventures with local contractors, but most of the physical construction was performed by the local subcontractors and laborers. Mahalingam and Levitt found that the local contractors in the Southeast Asian countries studied were not nearly as concerned about safety as the international contractors working in those markets. The local firms had access to a vast and inexpensive workforce with comparatively small worker's compensation insurance premiums and very little regulatory enforcement of safety practices. The differences in attitudes toward safety between the local subcontractors from Southeast Asian countries and the international contractors from industrialized regions negatively affected productivity—specifically, if international contractors deemed a task was being performed unsafely, they would stop working on it. Mahalingam and Levitt found that some western employers attempted to fine workers for failure to use prescribed safety equipment such as hardhats or for engaging in unsafe work practices. This caused serious tensions because the locals saw the stop work order or fine as unnecessary and were angry for the lost productivity or fine. The greater the differences in safety compliance, the more work stoppages and delayed completions one would expect when working in markets with such differing institutional norms.

When organizations from different countries work together on a global project, communication can also be a significant issue because of the different languages and different cultures. English (2002) studied the issues that arose out of communication problems on construction projects in South Africa. While all of the people involved were from the same region, the projects resembled those performed by international contractors because there were people from 31 different ethnicities represented on site. English found numerous conflicts among workers because they did not understand other workers' cultures, routines, and behaviors. Different languages were frequently a barrier to effective communication and often necessitated using a third party as an

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interpreter. Different cultural norms led to tension because what might be acceptable behavior for one person could be unacceptable for another.

Thus, problems in communication, differing safety norms, and cross-institutional differences on global projects contribute to "institutional disputes"—on top of the already large number of contractual and other conflicts that can occur on domestic construction projects. In a survey of construction professionals with experience in international projects, respondents indicated that cultural differences contributed the most to disputes (Chan and Tse 2003). Not only do these differences lead to additional disputes but national differences in attitudes about appropriate means for resolving disputes make them more difficult to resolve when they do occur. Considering all the additional difficulties and uncertainties that can arise on global projects it is not surprising that research on international joint ventures finds that about 40% fail to meet performance objectives (Beamish and Delios 1997).

Robust Project Network Organizational Design

Project organizational networks have been examined in design and construction from the perspectives of leadership (Chinowsky and Taylor 2007), innovation (Harty 2005; Taylor and Levitt 2004, 2007), information dependency (Pekericli et al. 2003), learning (Taylor et al. 2009), offshore outsourcing (Nayak and Taylor 2009), and boundary object technological change (Boland et al. 2007; Taylor 2007). With so many uncertainties threatening the project schedule, quality, and budget, Ortiz de Orue et al. (2009) investigated the application of robust design experimental methods to design project networks robust against organizational uncertainties. They developed an integrated approach to robust project network design which integrated robust design experimental techniques with a project organizational simulation tool. They found that the utilization of an integrated robust project network design approach extended the capability of project managers to design project networks that can perform reliably in dynamically uncertain project environments. Yet their research focused narrowly on a domestic project network design case. Some investigations of project networks have considered the global dimension of project network issues (Fong and Lung 2007; Taylor and Levitt 2007; Nayak and Taylor 2009). However, for the most part, our understanding of project organizational networks in design and construction is limited to domestic project networks.

The robust design method was developed by Taguchi with the objective of minimizing deviations in manufactured products by conducting experiments in the design phase (Taguchi and Clausing 1990). Under this ideology, consistency in quality was more beneficial than keeping the quality of the products within certain tolerances. If a product consistently varies from its specified dimension by a specific amount, the machines can simply be adjusted to correct for this. However, if products vary by varying amounts then the company would have to take apart its entire manufacturing process to analyze and discover which elements of the production system are causing the deviations. The same principles can apply to project network design. In the face of uncertainties, companies are better off assembling project teams that can perform consistently in a range of possible conditions rather than performing well only in ideal situations.

Taguchi developed a set of equations to isolate factor-setting effects on mean performance and to calculate a signal-to-noise ratio. A high signal-to-noise ratio indicates that the "signal" is strong relative to the "noise." In other words, the end product will remain consistent with the same inputs (signals) regardless of uncontrollable disturbances (noise). Taguchi's function for the "smaller the better" is used in this experiment since lower cost and duration values are more favorable (Roy 1990). An objective function is used to measure the overall performance of a project. It is a weighted average of the individual performance values, such as cost, time, and quality. This is discussed in detail later in this paper. Ortiz de Orue et al. (2009) applied Taguchi's robust design experimental methods (Taguchi and Clausing 1990) in conjunction with a project organizational simulation to develop a new framework for robust project network design. The virtual design team (VDT) simulation is a well-validated project organization simulation (Jin and Levitt 1996; Levitt et al. 1999) also used by Horii et al. (2005) in the study of Japanese and American cross-cultural project interactions. VDT includes four uncontrollable factors that can be used to vary the uncertainty levels on the project to calculate the most robust combination of controllable factor settings to design a robust project network, as demonstrated by Ortiz de Orue et al. (2009).

Uncontrollable factors in design and construction project networks include information exchange, noise, functional errors, and project errors. Information exchange is the need for communication with interdependent team members to coordinate a reciprocal interdependency (Thompson 1967) associated with the task. Noise refers to distractions in the workplace that take time to process but do not contribute to task completion. Functional errors are "exceptions" where additional information is required to complete the task (Galbraith 1974). Functional exceptions can result in the need for rework on that task without impacting others' tasks. Project errors are "interface exceptions" that may require rework on the task in question as well as on one or more interdependent tasks. The experiment of Ortiz de Orue et al. (2009) combined simulations of multiple scenarios for a given case study and detailed interviews with project managers. They found that the use of robust experimental methods to design robust project networks was not only possible but also extended the capabilities of project managers in predicting project performance. Project managers who implement the most robust set of controllable factors will design projects that perform most reliably in response to dynamic uncertainties in project environments. However, the integrated robust project network design method by Ortiz de Orue et al. (2009) has only been shown to improve the capabilities of project managers to plan domestic projects.

Robust Design of Global Project Networks

Whether working domestically or abroad, construction projects are becoming increasingly global—i.e., they increasingly involve participants from different countries. Managing the increased complexity, emerging uncertainties, and diversity of institutions on global projects is creating significant challenges for design and construction firms. Cross-institutional differences contribute to increased risks in completing projects on schedule, under budget, and within quality specifications. The construction engineering and management research community has examined and quantified the risks associated with international project execution (Han et al. 2007b; Hastak and Shaked 2000; Kim et al. 2008; Sonmez et al. 2007). Moreover, previous research has shown that organizational simulation software can be combined with robust design experimental techniques to design robust project

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networks capable of performing reliably in uncertain project conditions (Ortiz de Orue et al. 2009). However, the question of whether a robust domestic project network design can be generalized to be equally robust for a similar global project has not been investigated. This paper takes the first step toward understanding whether robust project network designs vary when generalized from a domestic project network to a global project network.

If robust project network design could be extended to enable project managers to predict performance of global projects from an organizational perspective, this would complement other risk-oriented predictive models in the literature. Moreover, robust global project network design could be used to examine project network scenarios before launching a project. Once validated on real projects (Thomsen et al. 1999), this approach would enable project managers to design their global project organizational network to perform reliably in the presence of the dynamic uncertainties that have been shown to plague global projects.

Research Methodology

To determine if a robust project network design differs in a global setting as opposed to a domestic setting, we replicated an existing robust project network design study and adjusted it for a multiinstitutional global setting. Researchers have criticized the reduction in the number of replication studies and have called for more replication research (Evanschitzky et al. 2007). Our simulation models replicated the simulation approach used by Horii et al. (2005) and the specific project activities and simulation approach used by Ortiz de Orue et al. (2009).

Virtual Design Team Simulation

The VDT simulation is an object-oriented discrete-event simulation that integrates project organizational models with project activity models. The term "virtual" in VDT refers to the fact that a user can build a virtual representation of a design team using the simulation software. It does not refer to the typical usage of the term virtual in the term "virtual teams" which describes geographically distributed groups of individuals simultaneously executing collaborative work through electronic media (Chinowsky and Rojas 2003). VDT is a well-documented and well-validated project organizational simulation which enabled us to obtain data about project durations, costs, and bottlenecks impacting quality [for more detail about VDT, see Jin and Levitt (1996); Levitt et al. (1999); Thomsen et al. (1999)]. VDT enables microlevel information processing and communication actions to be simulated and aggregated to produce output measures of progress relating to time, cost, and quality. The output is conditioned by the backlog of organizations, possibilities for missing meetings/deadlines, and quality risks that can occur when managers on the project become significantly backlogged. VDT modelers then interpret these backlogs and other risks to design interventions that they model and resimulate to improve project planning. We adopt the domestic project network simulation model created by Ortiz de Orue et al. (2009) to examine global project networks. The results from the replicated study, now scaled to the global project level, were compared with Ortiz de Orue et al.'s findings. The case study and all settings remained the same with the exception of the "uncontrollable factor" probabilities. The uncontrollable factor probabilities were adjusted from the project network model developed by Ortiz de Orue et al.: (1) in a test case scenario basing uncertainty factor levels on existing theories of cross-cultural communications and (2) to establish factor by factor sensitivity of scaling from designing domestic to global projects. This was performed to establish whether robust designs for global projects are likely to vary from robust designs for domestic projects, and how each uncertainty factor in the simulation impacts the point at which robust designs begin to diverge.

Replicated Case Study

The case study simulated was the renovation of a four-story public building, estimated to cost $11.5 million and last 13 months. The work included updating mechanical systems, establishing Americans with Disabilities Act (ADA) compliance, and preserving the building's historical value. The work was to be performed on all four floors simultaneously, though the first floor and second floor were outside the scope of this particular project. The budget for the third and fourth floors was $3.6 million. The third floor was scheduled to be completed in 184 days and the fourth floor in 179 days. There were eight domestically based subcontractors working together on these two floors, and they all reported to the prime "general" contractor. All personnel were assumed to have a medium experience level. Fig. 1 contains the model of the third floor renovation tasks, organizational assignments, planned meetings, rework, and task interdependency linkages to be simulated in the robust design experiment.

Adjusting Uncontrollable Factors for Global Project Network Test Case

The three uncontrollable factors modeled in VDT that existing literature suggests would differ at the global multiinstitutional project scale include information exchange probability (IEP), noise probability (NP), and functional error probability (FEP). IEP is the likelihood that someone will need to communicate with an employee from another firm regarding a linked task. NP is the likelihood that a worker will get distracted during the course of the work day. Distractions may include anything from personal phone calls, to helping peers or managers on other projects with work, to socializing. The FEP is the probability that there is an error in a given task and portions of the task have to be reworked. The baseline values and ranges for these probabilities are established in the simulation software user guide (ePM 2005). The baseline values we will use in this research are derived from the Ortiz and Orue et al. (2009) study: information exchange probability=0.4; noise probability=0.1; and functional error probability=0.075. These baseline values in the original case were determined based on the familiarity of the firms involved with the type of renovation project being constructed, the sophistication of the owner and subcontractors, and the project scope.

We first decreased the baseline IEP by 25%, from 0.4 to 0.3. In a global project team environment, where different subteams may speak different languages, communication across organizations is limited both in occurrence and effectiveness (English 2002). Information may also have to travel through a limited number of people who are capable of speaking multiple languages (Nayak and Taylor 2009). This restricts the flow of information in global multicultural projects. To address differences in NP we decreased the baseline probability of occurrence by 50%, from 0.10 to 0.05. The NP in VDT refers to socializing activities such as discussing the score of a sporting event from the previous day. With cultural barriers and culturally distinct interests in nonwork activities (e.g., national sporting interests in football, soccer, or cricket),

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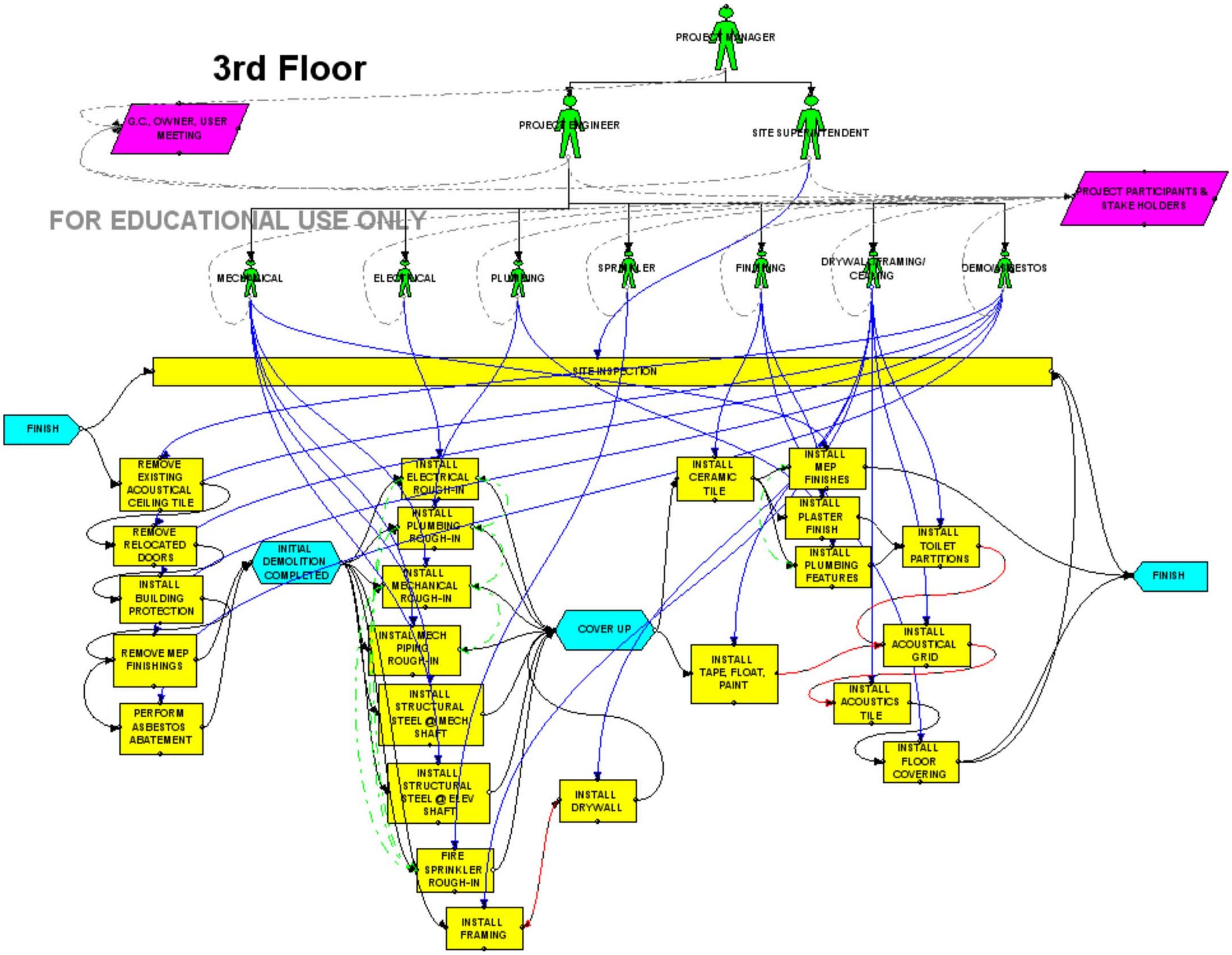

Fig. 1. Project task and organizational model for simulation of replicated case study [in this diagram of the organization and workflow from SimVision (the commercial version of VDT) hexagons represent milestones; boxes are tasks; solid arrows from actors to tasks are task assignments; solid arrows between tasks and milestones are sequence dependencies; dash-dotted two-way arrows between tasks are reciprocal interdependencies; dashed arrows between tasks are rework dependencies; rhomboids are meetings; and dash-dotted arrows from actors to meetings represent participation in those meetings]

distractions of this more social variety occur less frequently across organizations. This significantly minimizes the amount of distractions, or noise, in the workplace generated by cross-organizational socializing. Therefore, we expect the noise uncontrollable factor to decrease in global projects as compared to domestic projects. Lastly, we increased the baseline FEP by 75%, from 0.075 to 0.13125. VDT describes functional errors as those discovered by self-checking, peer review, or a supervisory review. According to Nayak and Taylor (2009), there are additional layers of quality control in global projects to deal with the additional errors that can arise from differences in standard work practices among countries. Engineers from different countries have different educational backgrounds and training which have been shown to lead to numerous conflicts related to design practice norms (Nayak and Taylor 2009). Because these conflicts are not governed by regulative standards, they can be difficult, costly, and time-consuming to resolve. Therefore, we increase the FEP for the case where multiple cultures work together on a global project. The assumed uncontrollable factor probabilities are summarized in Table 1 as the Level 2 values. Each Level 2 baseline uncontrollable factor level is increased and decreased by 50% in the Taguchi robust design experiment to obtain a set of interventions that perform reliably irrespective of uncontrollable factor levels. These increased and decreased values are described as the Level 1 and Level 3 values in the table.

Table 1. Domestic versus Global Uncontrollable Factor Error Probabilities

		Information exchange	Noise	Functional error	Project error
Level 1	Domestic	0.2000	0.1500	0.0375	0.1125
	Global	0.1500	0.0750	0.0656	0.1125
Level 2	Domestic	0.4000	0.1000	0.0750	0.0750
	Global	0.3000	0.0500	0.1313	0.0750
Level 3	Domestic	0.6000	0.0500	0.1125	0.0375
	Global	0.4500	0.0250	0.1969	0.0375

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Results

Uncontrollable Factor Level Sensitivity Analysis

The selected values in the global project test case are assumed based on indications in the literature on the impact of cross-institutional differences. These assumed global project network values may or may not lead to a different robust design. To understand the sensitivity of the robust design to changes in uncontrollable factor levels, we completed a factor by factor sensitivity analysis. We took the established uncertainty factor levels from the replicated case study as the baseline (these are indicated as domestic in Table 1). We then increased or decreased the Level 1, Level 2, and Level 3 values by increments of 1%. We increased or decreased the value depending on the direction of change suggested by the literature until the most robust combination of interventions changed.

Each 1% of change iteration in the sensitivity analysis required 375,000 simulation runs. This included 5,000 simulations averaged in VDT executed for each of 75 experimental scenarios (25 possible combinations of interventions $\times 3$ uncontrollable factor levels for each combination). We completed a sensitivity analysis for the FEP, the NP, and the IEP since these three error probabilities were determined most likely to be impacted by a move from domestic to global project organization. This sensitivity analysis was executed on a factor by factor basis. In other words, only the uncontrollable factor level being tested for sensitivity was adjusted by 1% across the three factor level settings; the other three uncontrollable factors remained constant at each level.

Global Project Network Test Case

There were three levels of backlogs for the global project scenario. At the highest level was the mechanical contractor. The drywall contractor, project engineer, and superintendent were at the next level, with all the other personnel at the lowest level. If we were performing the robust design of the project network organization without the benefit of the existing simulated case then we would either change the properties of just the mechanical contractor or all of the positions on the two highest levels. However, the purpose of this study was to examine differences between the global robust design results and the domestic robust design results, replicating the previous case study. Therefore we developed the robust design experiment using the same set of interventions by Ortiz de Orue et al. (2009). These included increasing or decreasing the crew size by 50% from the baseline of 10 workers and/or increasing or decreasing the skill level of the crew from the baseline medium skill level. After making these interventions, there was no longer a significant difference in backlog between the drywall contractor and the rest of the group; however the drywall contractor still had the second highest backlog after the mechanical contractor. Thus the interventions used for the domestic case were judged to be appropriate for the global case.

The 25 interventions used for the robust design experiment are combinations of an intervention for the drywall contractor and an intervention for the mechanical contractor. Each contractor has five different interventions with changes to the experience level of the crews and/or changes to the crew sizes. The interventions are summarized in Table 2. In this paper, each intervention will be named in a DxMy format, where x is the case number for the drywall contractor intervention and y is the case number of the mechanical contractor intervention. Only interventions that increased either the crew size or experience were considered. This eliminated four items from the matrix in Table 2, leaving the five cases described in the table. The duration, cost, or the quality of the project would not improve if neither the crew size nor experience level were increased.

Table 2. Intervention Scenarios for Each Contractor

		Labor experience		
		Low E_L	Medium E_M	High E_H
Number of workers	Low $W_L=5$	W_LE_L	W_LE_M	W_LE_H Case 5
	Medium $W_M=10$	W_ME_L	W_ME_M Baseline	W_ME_H Case 4
	High $W_H=15$	W_HE_L Case 1	W_HE_M Case 2	W_HE_H Case 3

The objective function was used to determine the most robust combination of controllable factors. It weighs each factor to arrive at an overall score for each combination of interventions. That function was derived through discussions with the project manager of the original case study project. The objective function was defined by the project duration, cost, and quality risk factors that make up the functional risk index (FRI) and the project risk index (PRI). The stringent project delivery date set up by the owner led to the project duration being the most heavily weighted value. The project manager assigned weights to each project metric based on the project's performance level that would satisfy the stakeholders' requirements, such as the delivery date, owner's budget, quality requirements, and regulation compliance such as the preservation of the historical character of the building and ADA requirements. The objective function was then used to calculate the mean project performance value for each of the 25 interventions at each of the uncontrollable factor levels. The objective function used was as follows:

$$y_i = 0.34\ \mathrm{PD}_i + 0.22\ \mathrm{PC}_i + 0.22\ \mathrm{FRI}_i + 0.22\ \mathrm{PRI}_i$$

where y_i=objective function value per combination; PC_i =project cost per combination; PD_i=project duration per combination; FRI_i=functional risk index per combination; and PRI_i =project risk index per combination.

We ran 5,000 trials of each intervention. The duration, cost, FRI, and PRI are summarized in Table 3. Table 4 normalizes the resulting values of each element of the objective function for each uncontrollable factor level. It also reports the sum of the means and the signal-to-noise ratio according to the Taguchi robust design experimental method for each combination of interventions.

Fig. 2 contains the signal-to-noise ratio graphs for the domestic monocultural and global multicultural project scenarios. A higher signal-to-noise (S/N) ratio indicates that the intervention is affected less by uncertainties and represents a more robust combination of interventions. In a robust design experiment, the highest point on each line is selected and combined to form the most robust set of interventions. The pattern of signal-to-noise ratios for the global scenario is qualitatively similar to that of the domestic scenario identified by Ortiz de Orue et al. (2009). However, even though the identical project was used as a basis for the simulation, we found that the most robust global project network designs differed significantly due to the required change in crew size of the mechanical contractor.

The most robust combination of interventions in the global multicultural project case is D2M5. The drywall crew size should

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Table 3. Global Project Network Robust Design Experiment Simulation Results

		Uncontrollable factor Level 1				Uncontrollable factor Level 2				Uncontrollable factor Level 3			
#	Intervention	Duration	Cost	FRI	PRI	Duration	Cost	FRI	PRI	Duration	Cost	FRI	PRI
1	D1M1	182.9	3714	0.493	0.340	185.3	3746	0.493	0.348	188.7	3804	0.494	0.368
2	D1M2	182.7	3701	0.492	0.342	184.8	3731	0.492	0.349	187.8	3767	0.494	0.367
3	D1M3	182.7	3694	0.494	0.342	184.7	3730	0.492	0.353	187.2	3747	0.493	0.370
4	D1M4	182.8	3685	0.492	0.344	184.9	3699	0.492	0.354	187.4	3730	0.494	0.368
5	D1M5	183.0	3671	0.493	0.342	185.2	3686	0.493	0.352	188.3	3715	0.493	0.370
6	D2M1	181.1	3703	0.494	0.341	183.3	3749	0.492	0.353	187.3	3774	0.494	0.369
7	D2M2	180.9	3694	0.493	0.343	183.0	3719	0.493	0.356	185.9	3760	0.493	0.371
8	D2M3	180.4	3691	0.493	0.345	182.5	3717	0.493	0.361	185.3	3734	0.493	0.378
9	D2M4	180.8	3669	0.493	0.345	182.8	3691	0.493	0.359	185.7	3723	0.493	0.377
10	D2M5	181.3	3656	0.491	0.343	183.5	3682	0.493	0.355	186.9	3703	0.493	0.373
11	D3M1	179.8	3706	0.493	0.346	182.1	3726	0.494	0.360	186.0	3763	0.493	0.375
12	D3M2	179.4	3685	0.492	0.348	181.3	3711	0.493	0.362	184.0	3749	0.494	0.377
13	D3M3	179.0	3681	0.493	0.347	180.8	3702	0.493	0.366	183.5	3734	0.494	0.385
14	D3M4	179.2	3657	0.493	0.351	181.2	3657	0.492	0.365	183.7	3706	0.492	0.384
15	D3M5	180.5	3649	0.493	0.351	182.5	3671	0.493	0.360	185.6	3692	0.493	0.382
16	D4M1	180.7	3688	0.492	0.346	182.8	3710	0.492	0.357	186.7	3756	0.494	0.378
17	D4M2	180.4	3675	0.493	0.346	182.5	3696	0.494	0.361	185.2	3742	0.494	0.380
18	D4M3	179.8	3659	0.494	0.349	181.9	3684	0.493	0.366	184.6	3715	0.493	0.381
19	D4M4	180.3	3652	0.493	0.350	182.2	3675	0.492	0.366	184.9	3695	0.493	0.385
20	D4M5	180.9	3637	0.492	0.348	183.0	3655	0.493	0.363	186.3	3678	0.493	0.380
21	D5M1	184.5	3675	0.492	0.348	186.4	3707	0.492	0.359	189.1	3769	0.494	0.379
22	D5M2	184.5	3664	0.492	0.351	186.1	3688	0.492	0.365	188.3	3732	0.493	0.383
23	D5M3	184.2	3663	0.492	0.352	185.6	3677	0.492	0.365	187.9	3709	0.493	0.383
24	D5M4	184.4	3641	0.493	0.353	185.9	3665	0.493	0.367	188.2	3688	0.493	0.385
25	D5M5	184.4	3627	0.492	0.364	186.8	3647	0.492	0.367	188.9	3670	0.493	0.382

be increased from 10 to 15 members, and the workforce should have a medium experience level. The mechanical crew should decrease from 10 to five workers and the workforce should have high experience level to produce the most reliable outcome for this project. Ortiz de Orue et al. (2009) indicated that the most robust combination of interventions in a monocultural domestic scenario was D2M3. In the monocultural domestic project case, the drywall contractor should increase their number of workers from 10 to 15 and have workers of medium experience level as well. The intervention also resulted in an increase in the experience level of the mechanical contractor but required an increase in workers from five to 10.

It was somewhat surprising that the robust design for a project with greater uncertainty would lead to a smaller crew sizing for the mechanical contractor. Closer inspection of the activities undertaken and the linkages between the activities by the drywall versus the mechanical contractor reveals an important difference that explains this apparent paradox. The drywall contractor depended only on one upstream activity (installation of the framing) and two downstream activities depended on the drywall firm (installation of ceramic tile and painting). These task interdependencies were sequential. However, the mechanical work was reciprocally interdependent with the activities of the electrical, plumbing, and fire proofing contractors and required two separate site visits to complete their work. Research has shown that addressing subgoal conflicts among concurrent reciprocally interdependent tasks is much more difficult than the sequential-only dependencies faced by the drywall contractor (Thompson 1967). Furthermore the activities of the mechanical contractor also had to contend with upstream and downstream task interdependencies. Given the more significant levels of uncertainty in the global project network case, fewer employees on site would require more time to execute the tasks but would generate far fewer errors and rework. Therefore, the best overall objective function for the robust global project network design resulted from having fewer highly experienced workers on the site.

Sensitivity of Robust Design to Domestic versus Global Project Network

This experiment demonstrates that, for the replicated test case, the robust design differs for global versus domestic project networks in important and surprising ways. However, we also asked the question of how they differed. We isolated each uncertainty factor and increased or decreased the error probability in 1% increments until the most robust combination of interventions changed. The point at which the most robust combination of interventions changed was assumed to be the point at which the domestic robust design was no longer appropriate. We found that the FEP can increase by between 9 and 10% before the robust project network design changes. We found that NP can decrease by 7 and 8% and that the IEP can decrease by 9 and 10% before the robust project network design changes. Fig. 3 contains the results of the sensitivity analysis of the three aforementioned uncontrollable factors.

These are relatively small changes in uncertainty compared to the tremendous amount of additional uncertainty involved with executing projects in global versus domestic scenarios. Furthermore, the sensitivity analyses were executed on a factor by factor basis. An increase in FEP by 9 and 10% would likely be coupled with decreases in NP and IEP. However, the analysis assumed no

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Table 4. Normalized Results for Robust Design Experiment Simulation Results

#	Intervention	Uncontrollable factor Level 1	Uncontrollable factor Level 2	Uncontrollable factor Level 3	S_m	S/N
1	D1M1	1,000.47	999.08	1,003.23	1,001,860	−60.0081
2	D1M2	1,000.14	997.43	998.83	997,598	−59.9896
3	D1M3	1,000.61	999.63	997.86	998,735	−59.9945
4	D1M4	1,000.64	998.77	996.50	997,273	−59.9881
5	D1M5	999.35	997.77	997.98	996,735	−59.9858
6	D2M1	997.52	998.17	999.50	996,794	−59.9861
7	D2M2	997.43	998.11	996.84	994,926	−59.9779
8	D2M3	997.58	1,000.12	998.30	997,337	−59.9884
9	D2M4	997.01	997.91	997.79	995,149	−59.9789
10	D2M5	995.01	996.22	996.47	991,816	−59.9643
11	D3M1	997.99	999.75	999.53	998,186	−59.9921
12	D3M2	996.81	998.16	996.67	994,432	−59.9758
13	D3M3	995.63	999.14	999.54	996,217	−59.9835
14	D3M4	997.10	996.15	996.78	993,365	−59.9711
15	D3M5	999.06	996.77	998.70	996,357	−59.9842
16	D4M1	998.15	997.37	1,002.59	998,746	−59.9946
17	D4M2	997.26	999.32	1,000.20	997,853	−59.9907
18	D4M3	997.52	1,000.11	997.65	996,858	−59.9863
19	D4M4	998.23	999.68	999.35	998,174	−59.9921
20	D4M5	996.74	998.58	997.98	995,542	−59.9806
21	D5M1	1,005.75	1,005.08	1,008.31	1,012,808	−60.0553
22	D5M2	1,007.00	1,007.06	1,006.56	1,013,796	−60.0595
23	D5M3	1,007.01	1,005.48	1,004.48	1,011,346	−60.0490
24	D5M4	1,007.15	1,006.99	1,004.95	1,012,770	−60.0551
25	D5M5	1,012.83	1,007.14	1,003.42	1,015,671	−60.0675

change to NP and IEP when assessing the sensitivity. Therefore far lower adjustments than identified in the sensitivity analyses would result in a change in the robust project network design. The reviewed literature on cross-institutional differences in global projects suggests a far greater adjustment in uncertainty levels. Therefore, this research suggests that project managers who do not design global project networks with appropriate uncontrollable factor level values are extremely likely to arrive at an incorrect robust project network design. The ability for the designed project network to perform robustly in the face of dynamic uncertainties would hence be impeded, perhaps significantly.

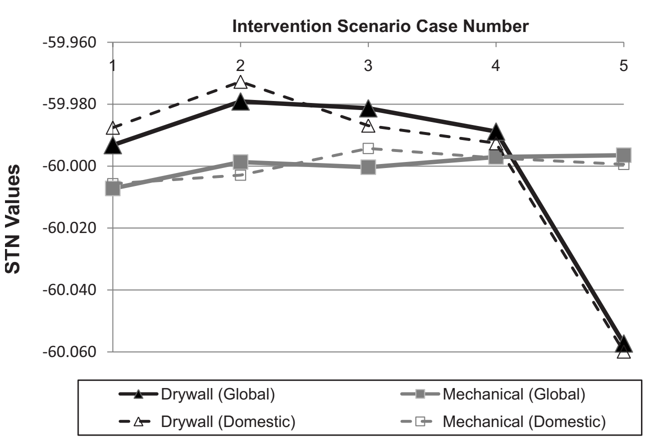

Fig. 2. Domestic versus global project network factor effects for signal-to-noise ratios

Summary and Contributions

Managing the increased complexity, emerging uncertainties, and diversity of institutions on global projects is creating significant challenges for AEC firms. Institutional differences lead to increased risks in completing projects on schedule, under budget, and within quality specifications because project managers do not know how the interactions among firms from multiple countries will affect the project. Previous research has shown that organizational simulation software can be combined with robust design experimental techniques to design robust project networks capable of performing reliably in uncertain conditions. This paper examined whether robust project network designs differ in do-

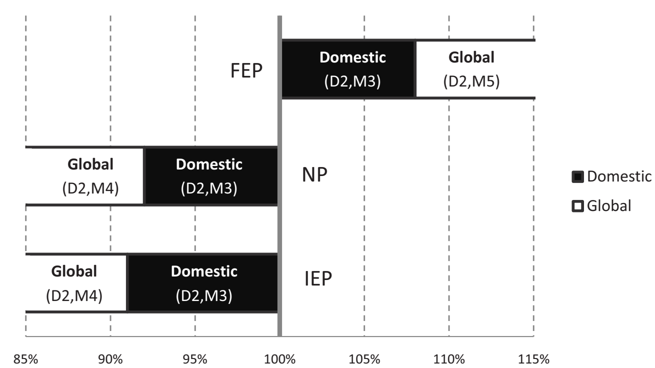

Fig. 3. Domestic versus global project network robust design sensitivity analyses

mestic versus global project environments. We replicated a case study on robust project network design (Ortiz de Orue et al. 2009) to ascertain whether and how cultural differences in global projects impact robust design outcomes. Our results demonstrate that robust project network designs will most likely differ when scaled to global project environments.

These initial findings contribute to the emerging and growing stream of research aimed at understanding and improving organizational performance on global design and construction projects. Firms' participation in global project networks is increasing both domestically and abroad. Participating in global project networks creates new uncertainties that firms must understand to design efficient project organizations. The global project network design insights developed in this paper represent a first step toward enabling global project managers to design project organizations that can reliably perform in highly uncertain global project environments. AEC firms are struggling to maintain and grow market share both domestically and abroad in the face of increasing global competitive pressures. We must continue to explore and develop innovative new tools, processes, and strategies that can improve the efficiency and profitability of global projects.

The global scale and technological complexity of modern projects require a fundamental reexamination of organization design for the field of project management. Future empirical research should attempt to validate the differences in uncontrollable factor probabilities assumed in this paper. Although these assumptions were grounded in published theories of cross-cultural interactions on projects, the reliability of the robust global project network design is a function of the range of uncertainties simulated. These could be validated using surveys of experienced global project managers to compare each uncontrollable factor in domestic versus global environments. In general we need more research to understand how operating outside a design or construction firm's national market or working with foreign partners domestically can lead to unanticipated cultural conflicts, contract misunderstandings, technology interoperability problems, misaligned work practices, and a host of other challenges. In many cases the current domestically derived approaches for managing projects will impair the project manager's ability to meet cost, schedule, and quality objectives in the global project context.

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