Achieving Multiple Project Objectives through Contingency Management

David N. Ford, P.E., M.ASCE

Abstract: Project managers use budgets to satisfy multiple objectives such as cost control, short durations, and high quality. Contingency funds are included in project budgets to manage risk and achieve project goals. Understanding how managers use budget contingencies requires a dynamic information processing model of how managers bridge the gap between high project complexity and limited managerial capacity. The results of collecting contingency management practices of real estate development project managers is reported and a dynamic simulation model of contingency management described. The model is used to test hypotheses of the effectiveness of aggressive and passive management strategies on cost, timeliness, and facility value. Managers were found to pursue general project objectives in their management of contingency. An aggressive strategy was found to be more robust but performed poorer than a passive strategy. Conclusions include the prevalence of trade-offs between robust and high-performance contingency management policies in construction projects and the importance of incorporating uncertainty into project planning and management.

DOI: 10.1061/(ASCE)0733-9364(2002)128:1(30)

CE Database keywords: Contingency; Project management; Cost control; Budgeting.

Introduction

Construction project performance is frequently measured in cost, time, and the value of the constructed facility. A traditional approach to managing multiple objectives applies a zero-sum-gain perspective in which the aggregate performance in these three dimensions is assumed to be fixed and trade-off decisions are used to achieve better performance in more important dimensions at the cost of poorer performance in less important dimensions. Accepting increased costs to reduce project durations by paying for overtime is perhaps the most common application of a zero-sum-gain approach to managing construction projects. But this perspective forces managers to choose among lower cost projects, shorter project durations, or better facilities and contrasts sharply with their desire to satisfy all three of these project objectives. Project managers seek tools and strategies that can simultaneously improve project performance in multiple dimensions.

Project budgets are one of the most important and widely used project management tools. Project complexity and the inherent uncertainty of the financial performance of constructed facilities, development funding, and the control of costs and schedules make exact budget needs impossible to forecast accurately. These same characteristics also cause projects to deviate from plans. Therefore, contingency funds are included in development budgets to provide managers with the flexibility required to address uncertainties and deviations that threaten achieving objectives (Diekmann et al. 1988). Budget contingencies are critical to meeting project objectives and can represent a large portion of a project budget (NASA 1996). Therefore, the effectiveness of contingency management can strongly influence project success. Large contingency sizes, the challenges of managing contingencies, and the central role of budget contingencies in determining project success make contingency management an important project management issue.

The next section describes the problem of understanding contingency management practice in light of the existing literature. Then the research approach and methods are described. The findings from fieldwork are used to develop hypotheses concerning the effectiveness of contingency management strategies. A description of the contingency management model is followed by the experiment design. The results of experiments are the basis for assessing the level of support for the hypotheses. Finally, implications of the results on project management are discussed, and conclusions are drawn.

Problem

Improving contingency management requires an understanding of how managers make budget contingency decisions and the impacts of those decisions on performance. Differences between the enormous complexity of projects and the limited capacity of humans to manage complexity (Sterman 1994; Simon 1995) create a problem of how to incorporate project complexity into management practice. Managers respond to this challenge by simplifying projects, building and applying formal models, and improving mental models. This work focuses on the third method. In the context of this work, mental models are internal representations of construction projects that managers use to control those projects (Senge 1990; Doyle and Ford 1998). This paper shows how practitioners apply this third approach in managing contingency by organizing information in relatively simple ways and using simple, generic decision-making processes.
Several questions must be answered to model and understand contingency management. What cost, time, and value objectives do managers seek to achieve with budget contingencies? How do managers organize contingency to facilitate decision making? What information processing rules do managers use to transform project conditions and objectives into contingency management decisions? What cognitive models and management strategies do they use? How well do these models and strategies fulfill contingency management objectives? What strategies are most effective under what project conditions? No clear picture of the models used in practice to manage contingencies currently exists to help answer these questions. Few formal theories of project budgeting and cost control are available. Cost estimating tools facilitate developing budgets but do not address the management of budgets or contingency during projects. Most cost accounting systems record and report historical costs but do not facilitate management by forecasting monetary requirements or directly influencing future performance. The literature identifies the types and purposes of contingencies (Yeо, 1990; Rosenau and Moran, 1993; Barrie and Paulson, 1984; Bennett, 1985; Clough, 1975; Lockhart and Roberds, 1996) and how contingency size can be estimated (Mak and Picken, 2000; Smith and Bohn, 1999; Yeо, 1990). Prescriptive models of contingency management are suggested (Murray and Ramsauer, 1983; Diekmann et al., 1988). But, the literature does not describe how contingencies are managed during projects or rigorously investigate the impacts of those practices on projects. Montoya-Weiss and Calantone (1994) reported that despite the importance of cost control to project success, the nature of cost as a driver of project success has been inadequately investigated. They conclude that research is needed that explains how management features impact performance. Inadequate understanding of these relationships prevents the design and testing of improved contingency and project management strategies. This research seeks to improve the understanding of how managers use budget contingencies to satisfy multiple project objectives by describing contingency management as practiced in a causal model and using that model to test the impacts of management strategies on performance.

Research Method

Descriptions of contingency management practice are not generally available, as described above and explained in the next section. Therefore, data was collected concerning contingency management by interviewing practitioners. Because management practices can vary across project types, and thereby obscure contingency management, the research focused on one project type—medium and large commercial real estate development projects. This reduced situational impacts on the sample, such as those caused by differences between office building and single family home development. The unit of analysis is a single contingency manager. Although medium to large real estate projects are typically managed by teams, it was initially assumed that individuals manage construction contingency funds. The data collected indicate that the primary responsibility, authority, and majority of contingency decisions are made by individuals, supporting this assumption. Therefore intrateam effects are ignored for the purposes of this study. The focus was further narrowed to budget contingencies managed by representatives of developing organizations to reduce the impacts of organizational differences in the sample, such as those caused by different construction contract types.

Data were collected through extended semistructured interviews of persons directly involved in and responsible for contingency management for developers. Informants were experienced managers with well-developed mental models of contingency management. With one exception, the interviews were conducted by telephone. The exception was conducted in person. Interviews lasted 60–90 min. The 35 interview questions were grouped into 4 categories: (1) background concerning the informant and projects managed; (2) the development of project contingency; (3) the use of contingency; and (4) the results of contingency management. Within the latter three categories, most questions focused on the “how” and “why” of contingency management to elicit descriptions of decision making and expose the fundamental causal relations of contingency management practice (Yin, 1994, p. 104). Detailed notes were taken of all interviews, but interviews were not tape recorded. This practice and the preservation of informant anonymity were done to encourage open discussion of all aspects of contingency management, especially potentially sensitive information.

Nine interviews were conducted in response to 11 requests for interviews. Informants represented regional, national, and international owners and developers based in the United States. The informants managed projects throughout the United States ranging from $500,000 to over $2 million. Approximately, two thirds of the informants were employees of a development organization. General contractors that provide construction management services for developers employed the other third of the informants. Interviews with these persons were conducted in the context of their construction management (versus contracting) roles.

The raw data was almost completely qualitative and only partially grouped into the four categories listed above due to the semistructured nature of the interviews. Therefore Yin’s (1994) organization and analysis of data around theoretical propositions were applied. Data for each informant were grouped into topics describing the theoretical propositions in the Problem section above:

- Managerial objectives of contingency management
- Means of addressing project complexity with cognitive limitations
- Information structures
- Decision-making processes.

Data about each topic was then compared across informants to identify dominant practices and exceptions to those dominant practices that suggested alternative or secondary perspectives and strategies. The consistency of the dominant practices allowed them to be aggregated into a single description of contingency management (described below) with relatively few secondary or alternative strategies.

Analysis results were used to develop two models of contingency management (Ford, 1997)—a purely descriptive model and a conceptual causal model in the form of causal loop diagrams (Sterman, 2000). This modeling helped abstract and describe how information was organized and processed by the informants and to build hypotheses about how contingency management strategies impact project performance. These models also formed the basis for the dynamic simulation model described here. The model was then tested for its ability to mimic contingency management decision making and used as an experimental tool to test the hypotheses.

Findings of Field Work

The findings from the interviews that are most pertinent to contingency management strategy and performance are described and
compared to the literature, which is predominantly prescriptive in nature. Although primarily qualitative, the data from the informants was quite consistent, and several important characteristics of contingency management practice were revealed in the consistency of responses. Findings with notes on relevant literature include:

- No evidence of formal or standardized models, the use of prescriptive contingency management methods (Ruskin 1981; Diekmann et al. 1988), or applications of advanced or objective analysis tools directed at contingency management was found.
- Contingency management practices are not organized by clearly defined procedures compared to many other managerial tasks, such as estimating and scheduling.
- Project management tools are used to generate input but not for decision support. For example, informants used scheduling software to assess project status relative to schedule objectives (milestones or deadlines) but not to guide contingency management responses to those assessments.
- Contingency management practices are not well documented or widely shared in sharp contrast to recommendations found in the literature (Hackney 1985; Jackson et al. 1985; Diekmann et al. 1988). This distinguishes contingency management, as practiced by the informants, from project management tools, such as the product hierarchies used by designers to define domains and identify interfaces that require coordination.
- Informants regularly hide contingency to prevent it from being “raided” by someone other than the person primarily responsible.
- Contingency managers use similar information organizations and decision-making processes to manage contingency. These structures and methods are much simpler than actual projects, managerial models of other aspects of projects such as critical path schedules, or several models found in the literature.

The lack of formal, standardized models, methods, and tools in practice reveal contingency management as a function performed primarily in the minds of managers (i.e., with mental models). Repeated references by informants to experience, judgment, and “gut feel” when asked to describe how they make contingency management decisions also testifies to the informal nature of these management processes. The informants indicated that the informal and individual nature of contingency management is not accidental or purely a result of project complexity. Informants consistently said that they intentionally keep contingency management tacit to retain control of contingency funds. Keeping contingency management tacit and even obfuscating contingency management appear to be means of protecting funds that are critical to achieving project objectives. This helps explain how practitioners address the question of who spends contingency funds, one of the two issues that Diekmann et al. (1988) consider central to controlling contingency. The simplified models apparently allow managers to address greater project complexity within the limits of their mental models. The information structures that managers were found to use to organize contingency management are described next, followed by the processes applied to generate contingency management decisions.

**Contingency Management Information Structures**

Consistent with the descriptions of others (Murray and Ramsaur 1983), evidence of multiple contingency funds with a general distinction between those used by business managers and those used by construction managers was found. This work focuses on the latter. The central information structure in construction contingency management is a set of four connected temporary funds or escrow accounts that are based on the manager’s goals. The data supports the literature that the primary role of contingency is to counterbalance the risk of spending beyond the project’s monetary resources due to deviations from project plans. However, the informants also identified other contingency management goals and a consistent ranking of priorities. The four contingency management objectives identified by the informants, ranked in descending order with supporting literature are:

1. Resolve emergencies: Protect against spending more than the budget by providing funds for future required unforeseen expenses, referred to here as emergencies (Mak and Picken 2000; Ruskin 1995; Williams 1995; Rosenau and Moran 1993; Hendrickson and Au 1989; Diekmann et al. 1988; Barrie and Paulson 1984).
2. Control the schedule: Assure completion by the project deadline by accelerating progress (Williams 1995; Rosenau and Moran 1993; Lockhart and Roberds 1996; Diekmann et al. 1988).
3. Improve the facility: Add value to the constructed facility, typically by design and scope changes or by adding to marketing or leasing programs beyond minimum project requirements.
4. Return excess contingency: Return contingency that remains after the project is completed to the developer or general contractor.

The first two objectives (resolve emergencies and control schedule) include many of the risks identified in the literature that contingencies are used to manage. Objectives one through three directly impact the constructed facility and reflect the traditional project management performance measures of cost to deliver the facility (resolving emergencies), duration (schedule control), and scope or quality (facility improvement). In contrast, the fourth objective of contingency management is related to managerial performance but not directly to project performance. Some managers value contingency funds remaining after project completion as an indicator of good management. A few managers sought to complete projects with as much contingency as possible but most considered this an indication of poor design, estimating, or project management. These unused funds are referred to as “excess” contingency, because they are beyond the contingency needs of the project.

As described, managers divide contingency funds into four accounts. These accounts are informal but rational separations of the total contingency into portions that are each sized to address a single contingency management objective. The priorities of the four accounts remained constant throughout a project and across the projects and managers encountered. But their contributions to project success are not equal. Successfully managing the first two objectives (emergencies and the schedule) is considered critical to project success, whereas the third and fourth objectives (improvements and excess contingency) are considered desirable but optional.

**Contingency Use Strategies and Processes**

With rare exception, exhausting contingency before the project is complete was considered a serious and grave condition (Diekmann et al. 1988), accompanied by strong negative impacts, including the potential loss of employment by managers. This was illustrated by the informant who said, “If there is contingency left I still have a job.” The speed at which managers are willing to
reallocate funds to lower priority uses, and thereby increase the risk of exhausting contingency funds, distinguished contingency management strategies. Consistent with the priority of the accounts, management efforts early in projects focus on reducing uncertainty by discovering the unexpected problems on the project (emergencies) and protecting their ability to meet project objectives by preserving contingency funds (Diekmann et al. 1988). Most project managers related their highest reluctance to use contingency with the higher risks from unknowns and future expenses that occur early in the project. Consistent with Ruskin (1995) and Murray and Ramsauer (1983), managers respond to decreasing uncertainty as projects progress by decreasing the funds considered necessary to address future emergencies.

As uncertainty decreases and deadlines approach, a majority of managers shift from primarily protecting contingencies for later use to a willingness to use contingencies to assure the timely completion of the project. For many project managers completing projects by their deadlines is sacrosanct. Repenning and Sterman (2000) report one engineer describing the importance of schedule performance in automobile development projects as “... the only thing they shoot you for is missing product launch... everything else is negotiable.” Several of the informants in this study described similar pressures to complete their construction projects on time. As projects approach their deadlines, the frequency of requests for work to accelerate construction increases. Therefore, funds held to address emergencies decrease but total contingency spending increases as projects approach their deadlines. This increases the risk of exhausting contingency, because the contingency remaining is shrinking while the rate of contingency use is increasing. Murray and Ramsauer (1983) consider the evaluation of the spending rate to manage this risk to be the most difficult and important aspect of contingency management. Pollock and Zeckhauser (1996) identified and modeled a similar increase in the use of limited emergency hospital spaces by doctors as a deadline for their use approached. This suggests that the project managers interviewed behave in ways that are generic to managers and not specific to construction project management.

The focus of contingency use shifts a second time as confidence in completing the project by the deadline increases. Improving the facility and accumulating unused contingency become more important in this final stage of the development project. This occurs very near and after the project deadline. In the absence of pressure to meet the project’s major design and time goals, contingency managers spend the remaining contingency on improvements or hold it for eventual return to the funding organization.

Hypotheses

Hypotheses were developed concerning how contingency management strategies impact the performance of different types of projects. Better performance is measured by more emergencies resolved, reduced delays, and facility improvement. Projects are described with their management difficulty, as described by the amount and nature of their uncertainty, and the project cost structure. Contingency management strategies are aggressive or passive. An aggressive strategy reallocates funds quickly, uses contingency to correct schedules before many emergencies have been discovered and resolved, and applies funds early to improve the facility. In contrast, a passive strategy reallocates slower, postpones using contingency until it must be used to meet critical objectives, and uses little funds for improvement until emergency and schedule objectives are met.

If sufficient contingency funds are available, all emergencies are resolved, deadlines are met, and facilities are improved. Under these conditions, many contingency management strategies are effective. But when resources constrain performance projects that are more difficult to manage (are uncertain and have higher costs), are expected to cost more, take longer, and improve facilities less. The first hypothesis predicts lower performance in projects that are more difficult to manage.

Hypotheses 1 (H1)—performance decreases with increasing management difficulty.

When project resources constrain performance, the impacts of strategy are expected to generate differences in performance. The second hypothesis predicts how projects managed with aggressive versus a passive strategies perform at given levels of project management difficulty. An aggressive strategy’s faster reallocation, earlier spending on schedule control and higher spending levels on improvements are expected to starve emergency resolution and schedule control efforts of needed funds more than a passive strategy. Therefore:

Hypotheses 2 (H2)—the percent of emergencies resolved are less and delays are larger using an aggressive strategy than when using a passive strategy for a fixed level of management difficulty.

When expenditures for improvements add more value to projects when applied earlier than when applied later (described in the next section), and because an aggressive strategy spends more contingency on improvements earlier than a passive strategy, an aggressive strategy is expected to add more value than a passive strategy. Therefore:

Hypotheses 3 (H3)—the value added using an aggressive strategy is larger than the value added using a passive strategy for a fixed level of management difficulty.

The final hypothesis predicts that project management difficulty has less impact on performance using an aggressive strategy than a passive strategy, suggesting that an aggressive strategy is more robust than a passive strategy.

Hypotheses 4 (H4)—performance decreases less as management difficulty increases using an aggressive strategy than a passive strategy.

Contingency Management Model

The contingency management model is less complex than actual projects or some project models. For example, emergencies are not disaggregated by type or cost and decision-making processes do not include statistical estimating. This is because the field data indicate that practitioners do not structure information this way or use these processes. Modeling describes the observed contingency management mental models. In this way, the interactions and potential flaws of contingency managers are captured better than in more complete and detailed models. The system dynamics methodology (Forrester 1961; Sterman 2000) was applied to model the delayed information feedback, changes in accumulations, and nonlinear relationships of contingency management. System dynamics is a methodology for studying and managing complex systems. This approach focuses on how performance evolves in response to the interactions of management decision making and development processes. System dynamics has been successfully used to explain failures in fast track implementation (Ford and Sterman 1998), impacts of changes (Cooper 1980), and other project management issues.

The model has four subsystems: (1) escrow accounts; (2) emergencies; (3) schedule control; and (4) facility improvement.
The escrow accounts subsystem simulates the monetary requirements, accumulations, and dynamic allocations of money among the four accounts and the use of contingency. The emergencies subsystem models the discovery and resolution of emergencies. The schedule control subsystem models the effects of emergencies on schedule performance and the perception and management of delays. The improvements subsystem simulates the addition of value to the facility by spending contingency funds. Each subsystem also models one form of contingency management performance. The simulation model is a set of nonlinear difference equations that describe the information structures and decision making processes used to manage contingency. Because no closed form solutions are known, the behavior of the system was simulated over time. In the description below, numbers in brackets [ ] refer to the model equations found in the appendix.

### Escrow Accounts Subsystem

The escrow accounts subsystem models how contingency funds in each account are dynamically reallocated in response to project and contingency conditions and how they are reduced by the use of funds. Fig. 1 shows the escrow accounts, reallocation flows, and uses of contingency. The accounts are arranged in descending priority from left to right. All the accounts have a similar generic structure [Eqs. (1)–(4)]. Surplus funds in higher-priority accounts are reallocated into lower-priority accounts [Eqs. (5)–(7)] and the emergency account can receive new contingency funds [Eq. (8)]. Each account can also “withdraw” money from the next lower-priority account, if the more important account does not have adequate funds [Eqs. (9)–(11)]. Reallocation flows between adjacent accounts are driven by the difference between the funds required by the higher priority escrow [Eqs. (15)–(17)] and that account’s current balance. Funds required by the facility improvement account are based on the relative importance of improvements and excess contingency to the project manager. Reallocation flows can also be constrained by the funds available in the supplying account. Reallocations are delayed and smoothed over time that managers require to perceive the imbalance in accounts, believe the reallocation is needed, and have confidence that the higher priority escrow is adequately funded to meet future demands. To reflect managerial protection of accounts early in projects, the time to reallocate in the downstream direction (emergencies to schedule to improvements to excess) is relatively long at the beginning of the project and decreases with project progress [Eq. (18)]. To reflect the much faster reallocation from lower to higher priority accounts the time to reallocate in the upstream direction is two weeks, reflecting only the estimated perception and response delay.

Contingency funds are spent to resolve emergencies [Eq. (12)], control schedules [Eq. (13)], or improve the facility [Eq. (14)]. Contingency use to resolve emergencies and accelerate the project are modeled as the product of the rates at which emergencies are resolved [Eq. (23)] or project delays are reduced [Eq. (28)] and the unit costs of emergency resolution or delay reduction. Contingency use for improvements is driven by the funds available for improvements and the manager’s willingness to use those funds. This willingness to improve the facility is described with the fraction of the improvements escrow account that the manager applies to improve the facility each week. The escrow accounts subsystem models excess contingency performance with the amount of excess contingency remaining after the project.

### Emergencies Subsystem

The emergencies subsystem models the reduction of uncertainty through the discovery and resolution of emergencies. At any time, each emergency is undiscovered [Eq. (19)], discovered but not resolved [Eq. (20)], or resolved [Eq. (21)]. Emergencies move from accumulations that are undiscovered, to those discovered, to those resolved. Emergencies are discovered at a rate dependent on the number of undiscovered emergencies and the progress of the project [Eq. (22)], which is modeled as the percent of the scheduled duration that has elapsed. The fraction of undiscovered emergencies that are discovered each week is not constant throughout a project but increases as more project conditions are exposed and uncertainty is reduced. The “S” shape of this function is based on the rate of uncertainty reduction proposed by Paulson (1976). Emergencies are resolved at a rate based on the number of discovered emergencies that remain unresolved and the average time required to resolve an emergency [Eq. (23)]. Resolving emergencies can also be constrained by the contingency funds available for that purpose. Contingency management performance in resolving emergencies is measured with the percent of emergencies resolved [Eq. (24)].
Schedule Control Subsystem

The schedule control subsystem simulates the accumulation and reduction of the expected delay in project completion. New delays increase the project’s completion delay [Eq. (25)]. Because the discovery of unforeseen conditions is a primary cause of project delays, new delays are modeled as the product of the emergency discovery rate and the number of days of delay caused by an average emergency [Eq. (27)]. New delays could also be modeled by linking the model to a more general project model (Cooper 1980, Ford and Sterman 1998). Managers typically respond to a smoothed measure of the project delay indicated by project conditions instead of the indicated delay [Eq. (26)], because high frequency fluctuations in expected completion delays and noise in schedule data can mislead managers (Forrester 1961). Managers do not typically attempt to bring a project back on schedule instantaneously but reduce delays over a period of time. In using contingency, this adjustment time is quite long early in a project, and contingency is used very sparingly to accelerate progress, because managers can apply tools other than contingency to improve schedule performance. But, consistent with the fieldwork, adjustment times shrink as the project approaches its deadline until schedule corrections are made as fast as possible. The time used to adjust the managed delay and correct schedule performance [Eq. (29)] reflects the manager’s response speed to changing project conditions and is used to describe different managerial strategies. Accelerating the project with contingency funds reduces the project completion delay [Eq. (25)]. The rate at which projects can reduce their completion delay is constrained by the money available to spend on acceleration and the size of the delay being managed [Eq. (28)]. Contingency management performance in controlling schedules is measured with the actual project duration as a percent of the planned duration [Eq. (30)].

Facility Improvement Subsystem

The facility improvement subsystem models the increase in facility value due to the use of contingency. Improvement costs for adding a given amount of value to a facility increase with project progress. Consider the value added to an office building by replacing narrow doors with wider ones to improve access and egress. This change is more expensive if made after the door design has been integrated with other building components than during conceptual design, even though the value added to the office building is the same at both times. The improvement is even more expensive if the narrow doors have been purchased and installed. Equivalently, the value added by each dollar of contingency used to improve the facility decreases as the project progresses. Improvement efficiency (value added per dollar spent) is estimated to decrease from 100 to 60% at a nonlinear rate. Added value accumulates at a rate based on the amount of contingency applied to improvement and the efficiency of contingency use for improvements at the time of use [Eq. (31)]. Contingency management performance in constructed facility improvement is measured with the total value added during the project.

Model Testing

Forrester and Senge (1980) suggest three types of tests of system dynamics models: (1) structural similarity to the actual system; (2) reasonable behavior over a wide range of input values; and (3) behavior similarity to actual systems. Basing the model on data collected during the fieldwork and the literature improves the model’s structural similarity to contingency management as practiced. Model behavior was tested with extreme input values such as no discovery of emergencies and very high values of excess contingency, as well as more typical conditions. Model behavior remains reasonable throughout these tests. Data on actual contingency management and behaviors are limited and primarily qualitative, preventing detailed model calibration and behavior comparison. However, the model’s behavior is consistent with informant descriptions of project behavior when estimates of variable values based on experience and the literature are used. According to the informants, contingency is used sparingly early in projects and primarily to resolve emergencies. The rate of use increases as the project approaches the deadline, with most expenditures being used to control schedule performance. Near and following the deadline, contingency is used primarily for facility improvement. Fig. 2 shows a simulation of contingency use for emergencies, schedule control, and improvements using typical parameter values for a medium sized ($1.5–3.0 million and 2-year planned duration) project that has been provided adequate contingency to achieve both critical objectives (resolve emergencies and finish by the deadline) and add value to the facility.

Fig. 2. Contingency use with adequate funds
The hypotheses were tested with experiments using the simulation model. Project types were characterized according to the difficulty of managing them with two characteristics: (1) the project’s uncertainty; and (2) cost structure. Uncertainty is described with the number of emergencies, timing of emergency discovery, average time to resolve an emergency, and delay generated by an emergency. Uncertainty increases as more emergencies are discovered later, take longer to resolve, and cause longer delays. The project’s cost structure is described with the unit costs of resolving an emergency and reducing the project delay by one day, and with the timing and speed of the decrease in facility improvement efficiency over the life of the project. More complex and expensive projects are considered more difficult to manage. Two levels of complexity are combined with two levels of cost to uniquely describe four project conditions that make a project more or less difficult to manage (Table 1).

Contingency management strategies are characterized as aggressive or passive with four management policies:

1. Evolution of contingency reallocation speed: how quickly and how far the fund reallocation time falls as the project progresses. In an aggressive strategy, this variable decreases linearly with progress to a minimum value of one week, reflecting a steady increase in flexibility in contingency use. In a passive strategy, the reallocation time remains high (representing slow reallocation) until 80% of the schedule has elapsed and then drops very quickly to three weeks after 90% of the schedule has elapsed.

2. Evolution of schedule perception and adjustment speed: intensity of attention and effort applied to schedule control. Both strategies start with a 5-week adjustment time. The aggressive strategy begins to decrease when just 10% of the schedule has elapsed and approaches 1 week when 80% has elapsed. But with a passive strategy, the adjustment time remains 5 weeks until 60% of the schedule has elapsed and then decreases exponentially to a minimum of 2 weeks.

3. Evolution of willingness to use contingency to control schedule: managerial resistance to using contingency early in the project in anticipation of schedule pressure as the deadline approaches. In the aggressive strategy, 100% of the funds are used when 75% of the schedule has elapsed; whereas, in the passive strategy, full use of available funds to control schedule does not occur until 95% of the scheduled duration has elapsed.

4. Escrow fraction used for improvement: confidence of managers that emergency and schedule objectives will be achieved and, therefore, funds can be spent on facility improvement without threatening the achievement of the two critical contingency management objectives. A higher fraction (25% per week) in the aggressive strategy uses funds for improvement faster than the lower fraction (5% per week) in the passive strategy.

Each strategy was applied to each of the four project management conditions. The priority of contingency management objectives requires different contingency levels to expose the impacts of strategies in different project conditions. Therefore, three sets of experiments were run based on an assumed project budget of $2 million: contingency of (1) 3.9% to reveal impacts on emergency performance; (2) 6.5% to reveal impacts on schedule performance; and (3) 9.0% to reveal impacts on improvement performance.

Results

Table 2 shows the performance of the aggressive and passive strategies in resolving emergencies, controlling the project schedule, and facility improvement for each of the four project management conditions, as well as the total change in performance across project management conditions.

Referring to Table 2, the percent of emergencies resolved decreases with each increase in management difficulty, using an aggressive strategy (91.0 to 47.5%) and a passive strategy (100 to 51.2%). Durations increase as a percent of planned duration with each increase in management difficulty, using an aggressive strategy (106.1 to 156.6%) and a passive strategy (100.0 to 157.7%). The value added generally decreases as project management difficulty increases, using either an aggressive or passive strategy. But the value added increases using an aggressive strategy.
($24,300 to $27,800) and a passive strategy ($4,300 to $4,600) from easy to difficult project management conditions. This supports H1 that performance decreases with increasing project management difficulty for the two critical performance dimensions and partially supports H1 in the facility improvement dimension.

The percentages of emergencies resolved using an aggressive strategy are less than the percentages using a passive strategy for each of the four project management conditions (91.0 < 100.0; 70.7 < 76.7; 61.0 < 68.0; 47.5 < 51.2). Therefore, the results support H2 that emergency performance using an aggressive strategy is worse than using a passive strategy for a fixed level of project management difficulty. Project durations using an aggressive strategy are greater than the same durations using a passive strategy for the three least difficult project management conditions (106.1 > 100.0; 116.5 > 114.2; 153.2 > 152.5) but less in the most difficult condition (156.6 < 157.7). This partially supports H2, that schedule performance using an aggressive strategy is worse than using a passive strategy for a fixed level of project management difficulty.

For each project management condition, the value added is greater using an aggressive strategy than using a passive strategy (53.5 > 37.1; 24.3 > 4.3; 27.8 > 4.6; 20.6 > 3.6). This supports H3 that the value added using an aggressive strategy is larger than the value added for a fixed level of project management difficulty.

The aggressive strategy reduces the percent of emergencies resolved 43.5% (91.0 to 47.5%), which is less than the 48.8% reduction (100 to 51.2%), using a passive strategy as project management conditions become more difficult. The aggressive strategy increased project durations as a percent of initial deadlines by 50.5% (106.1 to 156.6%), which is less than the 57.7% increase (100 to 157.7%), using a passive strategy. The aggressive strategy decreased the value added by 61.5% ($53,500 to $20,600) as project difficulty conditions increased, which is less than the 90.2% decrease ($37,100 to $3,600), using a passive strategy. This supports H4 that performance decreases less as project management difficulty increases using an aggressive strategy than using a passive strategy.

**Discussion**

The contingency management practices that were found and modeled both facilitate project management and create challenges for managers. The four escrow accounts and generic processes simplify contingency management and automate some managerial cognition. The released cognitive capacity is partially used to address the dynamic aspects of contingency such as the evolutions of adjustment times. This improvement of contingency manager’s mental models achieves two objectives: (1) it incorporates project complexity into management; and (2) it protects contingency funds from others by keeping contingency management informal and tacit. The four objectives represented by the escrow accounts also create conflicting incentives concerning when construction managers should optimally spend how much contingency. Managers are simultaneously encouraged to not spend funds early to effectively manage risk (emergencies) and spend funds at the project’s end to assure timely completion (schedule) but also to spend funds early to add the most value to the facility (improvements) and possibly not spend funds at all (excess contingency). The decision-making challenge is exacerbated by the priorities of the objectives, which encourage managers to resist spending funds on value adding improvements relatively early, exactly when those investments could provide the most benefit. Additionally, because surplus contingency from resolving emergencies and completing projects on time is only identified at the end of the project, relatively little value can be added to the facility with these funds. Ruskin (1995) suggests that this behavior is problematic. The model explicitly describes a causal structure that can explain why this behavior occurs.

Strategies that can address the challenges of contingency management, retain the benefits outlined above, and improve total project performance are not obvious. A passive strategy was found to perform better than an aggressive strategy under most conditions in the two performance dimensions identified as critical (emergencies and schedule control). But an aggressive strategy is more robust in the same two performance dimensions and, therefore, is better able to absorb changes in project conditions. These results suggest that project managers can choose between better performance with fragility or lower performance with robustness. Repenning (2000) identified the same performance/robustness trade-off in automobile development projects. Neither a higher-performing or more robust strategy is inherently superior. A project with little risk of changes that degrade performance can take advantage of the better performance available by applying a passive strategy, whereas more variable project conditions recommend an aggressive, robust strategy. Therefore, project managers can improve their contingency management strategy selection and design by identifying and quantifying project uncertainty and the variability in management conditions it may generate. Recent advances in valuing uncertain future conditions, such as real options theory (Amran and Kulatilaka 1999), may prove useful in evaluating strategy alternatives dominated by uncertainty.
Conclusions

Contingency management practices were collected and used to develop hypotheses concerning how project management conditions and contingency management strategies interact to impact performance. A dynamic behavioral simulation model of contingency management was built and used to test the hypotheses. Managers were found to disaggregate contingency into escrow accounts to simplify contingency management, replacing a single tightly-connected multiple-objective problem with a set of simpler, linked, single-objective problems. Escrow accounts also facilitated the development and use of generic decision-making processes, allowing managers to apply a single set of policies to four accounts instead of using a larger, more complex decision-making process. In these ways, the mental models used by managers simplify the multiple objective management problem that lies at the heart of contingency management.

The results of hypothesis testing generally support better performance but less robustness using a passive strategy when compared to using an aggressive strategy. Results show that research in contingency management and construction strategies must explicitly include the dynamic interactions among system components to capture critical drivers of performance. This work also supports the quantification and valuation of uncertainty in construction projects as an important area of research. Based on this work, practitioners are advised to identify the sources and characteristics of uncertainty in their projects and incorporate that understanding into project management. Continuing to improve the understanding of how contingency management practices impact performance can facilitate the design of strategies that improve construction project performance.

Appendix

Escrow Accounts Subsystems

\[ (d/dt)A_e = -a_{c,e} + a_{s,e} - u_e + a_n \]  
(1)

\[ (d/dt)A_s = +a_{c,s} - a_{s,e} - a_{s,i} + a_{i,s} - u_s \]  
(2)

\[ (d/dt)A_i = +a_{c,i} - a_{i,s} - a_{i,i} + a_{s,s} - u_i \]  
(3)

\[ (d/dt)A_k = +a_{i,i} - a_{i,i} \]  
(4)

\[ a_{c,i} = \text{Max}(0, \text{Min}(A_e, (A_e - r_e)/t_d)) \]  
(5)

\[ a_{s,i} = \text{Max}(0, \text{Min}(A_s, (A_s - r_s)/t_d)) \]  
(6)

\[ a_{i,i} = \text{Max}(0, \text{Min}(A_i, (A_i - r_i)/t_d)) \]  
(7)

\[ a_n = \text{Max}(0, (r_e - A_e) - a_{c,e}) \]  
(8)

\[ a_{c,i} = \text{Max}(0, \text{Min}(A_s, (r_e - A_s)/t_u)) \]  
(9)

\[ a_{i,i} = \text{Max}(0, \text{Min}(A_i, (r_i - A_i)/t_u)) \]  
(10)

\[ a_{i,i} = \text{Max}(0, \text{Min}(A_s, (r_i - A_i)/t_u)) \]  
(11)

\[ u_e = e_e * c_e \]  
(12)

\[ u_s = s_e * c_e \]  
(13)

\[ u_i = A_i * w_i \]  
(14)

\[ r_e = E_d * c_e \]  
(15)

\[ r_i = D_m * c_s \]  
(16)

\[ r_i = V_{i,s} * A_s \]  
(17)

\[ t_d = f_e(t/t_i) \]  
(18)

where

\[ A_j = \text{escrow account ($)} \text{ where } j \in \{\text{emergency (e), schedule (s), improvement (i), excess (x)}\} \]  
(19)

\[ a_{j,k} = \text{allocation of contingency funds from account } j \text{ to account } k (\$/week) \text{ where } j,k \in \{e,s,i,x\} \text{ and } j \neq k \]  
(20)

\[ a_n = \text{new funds allocated to contingency (\$/week)} \]  
(21)

\[ u_j = \text{use of contingency for purpose } j (\$/week) \text{ where } j \in \{e,s,i\} \]  
(22)

\[ r_j = \text{funds required in escrow account } j (\$/week) \text{ where } j \in \{e,s,i\} \]  
(23)

\[ t_d = \text{average time to allocate funds in downstream direction (weeks)} \]  
(24)

\[ t_u = \text{average time to allocate funds in upstream direction (weeks)} \]  
(25)

\[ e_e = \text{rate of resolving emergencies (emergencies/week)} \]  
(26)

\[ s = \text{rate of reduction in project’s delays (days/week)} \]  
(27)

\[ c_e = \text{unit cost of solving an emergency (\$/emergency)} \]  
(28)

\[ c_s = \text{unit cost of reducing project delay (\$/day)} \]  
(29)

\[ f_e = \text{effect of project progress on time to allocate funds downstream (weeks)} \]  
(30)

\[ w_i = \text{Willingness to use contingency to improve facility (%) per week} \]  
(31)

\[ t = \text{time elapsed (weeks)} \]  
(32)

\[ t_r = \text{completion target (weeks)} \]  
(33)

\[ V_{i,s} = \text{value of use of contingency for improvements versus value as excess contingency (dimensionless)} \]  
(34)

Emergency Subsystem

\[ (d/dt)E_u = -e_d \]  
(35)

\[ (d/dt)E_d = +e_d - e_e \]  
(36)

\[ (d/dt)E_e = +e_e \]  
(37)

\[ e_d = E_u * f_d(t/t_i) \]  
(38)

\[ e_e = \text{Min}(A_e/(c_e * dt), E_d/t_e) \]  
(39)

\[ p_e = E_i/(E_u + E_e + E_i) \]  
(40)

where

\[ E_u = \text{emergencies not discovered (emergencies)} \]  
(41)

\[ E_d = \text{emergencies discovered but not solved (emergencies)} \]  
(42)

\[ E_e = \text{emergencies resolved (emergencies)} \]  
(43)

\[ e_d = \text{rate of discovery of emergencies (emergencies/week)} \]  
(44)

\[ f_d = \text{effect of progress on discovery of emergencies (%) per week} \]  
(45)

\[ t_e = \text{average time to resolve an emergency (weeks)} \]  
(46)

\[ p_e = \text{performance of contingency management in resolving emergencies (%)} \]  
(47)

\[ dt = \text{simulation time step} \]  
(48)

Schedule Control Subsystem

\[ (d/dt)D_a = +d - s \]  
(49)

\[ (d/dt)D_m = (D_m - D_m)/\tau_m \]  
(50)

\[ d = e_d * d_e \]  
(51)

\[ s = \text{Min}(D_d/(d/\tau_d), A_j/(c_s * dt), (D_m/\tau_m) * w_j(t/t_i)) \]  
(52)

\[ \tau_m = f_s(t/t_i) \]  
(53)
$$p_s = \frac{(t_I + D_{a,I}/w)\tau}{t_I}$$

where

- $D_a$ = actual project completion delay (days)
- $D_m$ = managed project completion delay (days)
- $d$ = addition of completion delay (days/week)
- $d_e$ = delay generated by an emergency (days/emergency)
- $s$ = reduction of completion delay (days/week)
- $\tau_m$ = average time to perceive and adjust project delay (weeks)
- $f_s$ = effect of project progress on time to perceive and adjust project delay (weeks)
- $w_s$ = willingness to use contingency for schedule control (%)
- $p_s$ = contingency management performance in schedule control (%)
- $D_{a,I}$ = actual project completion delay at project deadline (weeks)
- $w$ = length of work week (days/week)

Improvements Subsystem

$$\frac{d}{dt}V_I = u_i \cdot f_i \cdot \frac{t_I}{t_I}$$

where

- $V_I$ = value added to facility by use of contingency for improvements ($)$
- $f_i$ = effect of project progress on facility improvement efficiency ($\$ of value/$ of contingency)

References


