IMPACT OF SCHEDULE AND BUDGET PRESSURE ON SOFTWARE DEVELOPMENT PERFORMANCE

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Tara Thomas is a junior at The University of Michigan majoring in Organizational Studies and Economics. She has a strong interest in creating a stronger bond between the non profit sector and the for profit world. She plans on pursuing a career combining these two interests upon graduation. She is especially interested in international development issues. After gaining more exposure in the field, she would like to return to academia to pursue a joint Masters in Business Administration and Social Work. This project has given Ms. Thomas invaluable insight into some of the financial issues that face the for profit world and she would like to thank the other two authors for giving her the opportunity to be part of such an exciting project.
IMPACT OF SCHEDULE AND BUDGET PRESSURE ON SOFTWARE DEVELOPMENT PERFORMANCE

ABSTRACT

As excessive schedule and budget compression becomes the norm in today’s software industry, an understanding of the impact of schedule and budget pressures on software development performance is crucial for effective management strategies. This study introduced related behavioral perspectives to explore the mechanism of the pressure effect. Based on the mechanism, research models were developed to predict the effects of schedule and budget pressures on major dimensions of project performance: cycle time, effort and quality. The research models were empirically tested with data from a $25 billion/year international IT (information technology) firm. We found that a U-shaped relationship existed between schedule pressure and cycle time. Similar relationships were seen between budget pressure and development time and effort. Budget pressure had a significant impact on software quality, whereas schedule pressure did not significantly affect software quality. The theoretical development and empirical findings of this study contribute to optimal budget and deadline setting policies in software development industry. They also help reconcile conflicting views from the literature.

KEYWORDS: schedule pressure, budget pressure, project performance, software development time, software development effort, software quality
1. INTRODUCTION

In the software development industry schedule and cost overruns have become a major plague. According to the Standish Report (Standish Group, 2000), only 28% of all software projects were completed on time and on budget. The remainder incurred 63% schedule overruns and 45% budget overruns on average. American companies paid extra billions of dollars for the delayed or over-budget projects (Standish Group, 1995). Obviously, timely and cost-effective software development has been a critical issue in both management information systems (MIS) research and the software industry.

A crucial factor in the duration and cost of software development projects is schedule and budget pressures. Schedule and budget pressures are mainly created by the discrepancy between development team estimated schedule and budget and management reduced schedule and budget (Weinberg, 1971; Yourdon, 1997). Behavioral scientists have long recognized that pressure has a significant impact on individual’s task performance (e.g., Yerkes and Dodson, 1908). In a human-centric process such as software development (Chiang & Mookerjee, 2004), individual performance will consequently affect the outcome of a software project. As excessive schedule and budget compression becomes the norm in today’s software industry (Yourdon, 1997), an understanding of when and how schedule and budget pressures will positively or negatively affect project performance is critical for timely and cost-effective software development strategies.

Although several MIS researchers have touched on the topic of schedule or budget pressure, there is a lack of consistent views in the field. Some studies indicated a positive impact of pressure on project performance (e.g., Jeffery, 1987; Kitchenham, 1992; Austin, 2001), while others suggested a negative effect (e.g., Putnam, 1978; Boehm, 1981; Abdel-Hamid, 1988;
Mukhopadhyay et al., 1992; Srinivasan & Fisher, 1995). We see four issues behind the conflicting views. First, few studies took a behavioral perspective and probed into the mechanism of the pressure effect. Secondly, related studies have not established a reliable measure of schedule or budget pressure. Thirdly, past research often looked at only a subset of the outcome factors rather than all three dimensions of project performance: cost, cycle time and quality (Abdel-Hamid, 1999). Finally, the empirical data examined by related studies were often confounded by variables such as the “padding” effect (development teams slacken their estimates by a safe factor) (Yourdon, 1997).

The objective of this study is to address the four issues raised above and provide a unified view of the impacts of schedule and budget pressures on software development performance. Specifically, we introduced related behavioral perspectives to explain the mechanism of the pressure effect. The mechanism then provided a framework to evaluate and integrate seemingly inconsistent findings from the literature. We constructed measures of schedule and budget pressures in the context of software development projects. To gain a complete view of the impacts on project performance, the research models of this study included all main outcome factors: cost, cycle time and quality as the dependent variables. Finally, this study empirically tested the relationship between pressure and project performance with data collected on software projects conducted between 1984 and 2004 from a $25 billion/year international technology firm. The dataset had adequate information to control for several critical confounding variables, such as the padding effect, process maturity, product design complexity and user requirements ambiguity.

The scope of the current study is specified by the following concepts and research questions. Schedule and budget pressures are defined by the discrepancy between development
team estimated schedule and budget and management reduced schedule and budget. Software development refers to all the stages starting from initial design through final product acceptance testing. Performance of software development projects is defined by three main outcome factors: cost, cycle time and quality (Abdel-Hamid, 1999). Based on the tradition of software engineering research, cost is evaluated by the total number of person months logged by the development team (Hu et al., 1998) and is referred to as development effort throughout this paper. Cycle time, or duration of a development project, is measured by the number of calendar days elapsed from the first day of design to final customer acceptance of the product. Quality is assessed by the number of lines of source code in the product divided by the sum of defects found in system and acceptance testing (Harter et al. 2000). This inversed defect density (Fenton and Pfleeger 1997) offers a more intuitive understanding of the quality values: higher values mean better performance. Our research objective is operationalized into the six research questions below:

1. What is the impact of schedule pressure on software development cycle time?
2. What is the impact of schedule pressure on software development effort?
3. What is the impact of schedule pressure on software quality?
4. What is the impact of budget pressure on software development cycle time?
5. What is the impact of budget pressure on software development effort?
6. What is the impact of budget pressure on software development quality?

The rest of the paper is organized as follows. In the immediate following section, we will review the literature. The section afterwards will introduce behavioral perspectives and explore
the mechanism of the pressure effect. In section four, we will discuss hypotheses, research models and measures of key concepts. The fifth section will describe our research methodology. Section six will present the statistical analysis and results. In the last section, we will draw implications and conclusion on the basis of the findings.

2. LITERATURE REVIEW

In the literature, researchers have not reached a consensus regarding the impacts of schedule or budget pressure on project performance. Some studies saw a monotonic negative relationship between pressure and project performance. For example, Putnam’s Rayleigh curve model (Putnam, 1978) suggested that decrease of allocated development time would increase development effort. Similarly, the COnstructive COst MOdel (COCOMO) (Boehm, 1981) predicted that any compression from a nominal schedule would incur more cost. In addition, Abdel-Hamid and his colleagues incorporated schedule pressure as a factor in decrease of software quality and productivity in their dynamics of software development model (1988, 1989a, 1989b, 1993, 1999). With respect to budget pressure, several researchers have argued that compressed budget forces software developers to finish projects quickly. Consequently, budget pressure can lower productivity of developers and raise the actual cost of a project (e.g., Mukhopadhyay et al., 1992; Srinivasan & Fisher, 1995).

In contrast to the negative view, several studies indicated a positive relationship between pressure and project performance. In an empirical investigation about development schedule and effort (Jeffery, 1987), it was found that compressed schedule could lead to lower development effort. In a subsequent study (Kitchenham, 1992), similar result was seen in another data set. Even in the COCOMO data set there were schedule compressed projects that were also effort
compressed (Kitchenham, 1992), although COCOMO predicted a negative relationship between the two. In an analytical study about schedule pressure and software quality (Austin, 2001), it was argued that a software developer was less likely to cut corners if fewer of his/her peers could meet the deadline. Therefore, subtracting time from team estimated schedule so that few developers can regularly meet the deadlines could improve the quality of a project. Overall, the analytical model implied a positive relationship between schedule pressure and software quality.

In summary, previous studies have presented opposite views about the impacts of schedule or budget pressure on project performance. An important reason for the conflicting predictions is a lack of behavioral perspectives in the reviewed studies. Behavioral scientists have recognized that pressure can have positive and negative effects on performance simultaneously. The opposite effects are mediated by two sets of variables (Parkinson, 1957; McGrath, 1976; DeMarco, 1982; Yourdon, 1997). Different levels of pressure can generate varied conflations of the mediating effects (Sternman, 2000). Consequently, people may observe distinctive patterns of the relationship between pressure and performance.

3. MECHANISM OF THE PRESSURE EFFECT

Behavioral scientists realize that task goals, excitement of a task, work time and work speed are variables mediating the positive relationship between pressure and individual performance. Parkinson’s Law (Parkinson, 1957) states “work expands so as to fill the time available for its completion.” It implies that task goals have a reinforcing effect between pressure and performance: higher level of pressure leads to higher goals, and higher goals generate better performance (Gutierrez and Kouvelis, 1991). Excitement of a task was recognized as another positive mediator (McGrath, 1976). An elevated level of pressure can increase the excitement of
a task, which in turn encourages more effort from workers. In addition to the subtle psychological effects, work time (Yourdon, 1997) and work speed (DeMarco, 1982) are strong factors in the positive impacts of schedule pressure. Under tight schedules, people simply work faster and longer to boost the output (DeMarco, 1982; Yourdon, 1997).

Meanwhile, task difficulty, stress (McGrath, 1976), fatigue (Yourdon, 1997) and negligence (DeMarco, 1982) have been found to mediate the negative impacts of pressure on performance. Their effects can play out through two processes. On the one hand, pressure tends to make people feel stressed, exhausted and less effective. The negative feelings cause suboptimal performance (McGrath, 1976). On the other hand, while the positive mediators (task goals, excitement, work time and work speed) help performance, they can aggravate the negative mediating effects. It is natural for people to burn out or cut corners when they have unrealistic goals, work long hours or in a rush (Abdel-Hamid, 1989; DeMarco, 1982; Yourdon, 1997).

The relationship between pressure and performance depends on the relative strength of the positive and negative mediating effects. When pressure level is low, positive effects of task goals, excitement, work time and work speed dominate the relationship. However, with increasing level of pressure, the negative impacts of task difficulty, stress, fatigue and negligence gain strength, eventually offset the positive mediating effects (Sternman, 2000). Overall, the aggregation of the opposite effects approximates an inverse U-shaped relationship between pressure and performance (e.g., Yerkes and Dodson, 1908; Stennett, 1957; Berry, 1962; Weinberg, 1971; McGrath, 1976; Sjoberg, 1977; French et al. 1982). Figure 1 illustrates the mechanism of the pressure effect.

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Insert figure 1 about here

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The mechanism provides a framework to reconcile the seemingly inconsistent predictions in the literature. We see that the opposite monotonic views reflect portions of the large U-shaped function. Studies proposing negative impacts of pressure (Putnam, 1978; Boehm, 1981; Abdel-Hamid, 1988; Mukhopadhyay et al., 1992; Srinivasan & Fisher, 1995) imply the situation when negative effects dominate the pressure-performance relationship. On the other hand, observations of positive effects of pressure (Jeffery, 1987; Kitchenham, 1992; Austin, 2001) indicate the situation when the positive mediating effects are relatively strong. Since the U-shaped relationship captures the large picture between schedule or budget pressure and project performance, this study employ the U-shaped view as the rationale for hypotheses and analysis.

4. RESEARCH MODELS AND HYPOTHESES

Construct Measures

Schedule and budget pressure

Schedule and budget pressures are the independent variables of this research. In the scope of this study, we see three requirements for effective measures of schedule and budget pressures. First, according to their definition, proper measures should indicate the discrepancy between development team estimated schedule or budget and the management constrained schedule or budget. Secondly, measures should be taken at the onset of a project rather than at the completion of it. The mechanism of the pressure effect implies that people have to first feel the pressure, and then respond to it through their performance. Thirdly, they should be quantitatively comparable across projects and teams. This requires a formula that can standardize and quantify the psychology of a development team.
The literature has not established a consistent measure for schedule or budget pressure. Schedule pressure has been assessed by the elapsed time of a project (e.g., Putnam 1978; Boehm, 1981), the ratio between actual elapsed time and estimated elapsed time (e.g., Jeffery, 1987), the ratio between scheduled completion date and forecasted completion date (Abdel-Hamid et al., 1993), or self-reported values by software developers and managers (Weinberg, 1971). None of these measures can satisfy the three requirements discussed above. The metrics based on actual elapsed time (Putnam 1978; Boehm, 1981; Jeffery, 1987) are *post hoc* rather than *ex ante*. They do not indicate the pressure level prior to performance. The self-reported values (Weinberg, 1971) depend on people’s subjective opinions. It is difficult to compare personal assessments across development teams.

In related studies, “budget constraint” or “cost constraint” usually means the total amount of capital available to a project (e.g., Boehm, 1981). Similar to previous measures of schedule pressure, they are not adequate indicators of the concept of budget pressure examined by this study.

The diverse measures of schedule or budget pressure are one of the causes for the inconsistent views in the literature. As another effort to unify the literature, we developed our own measures of schedule and budget pressure:

Schedule Pressure = \(\frac{\text{Team Estimated Cycle Time} - \text{Management Shortened Cycle Time}}{\text{Team Estimated Cycle Time}}\)

Budget Pressure = \(\frac{\text{Team Estimated Budget} - \text{Management Reduced Budget}}{\text{Team Estimated Budget}}\)
Here, cycle time means the number of calendar days elapsed from the first day of design to final customer acceptance of the product. Budget refers to the number of person months of effort allocated for a development project. At the research site, development teams first proposed their estimated cycle time and budget with the assistant of an estimation tool. During the negotiations between software management and clients, team estimated cycle time and budget were usually reduced. Management shortened cycle time and reduced budget are recorded in the final contracts.

The numerators of the two measures reflect the discrepancy between team estimates and management reduced cycle time or budget. In terms of timing, both team estimates and management negotiated contracts occur before the launch of a project. Taking the ratio between the discrepancy and the team estimates can quantify and standardize pressure levels across projects and teams.

**Cycle time**

Cycle time is one dimension of the project performance. It is the time to develop the software product, i.e., the number of calendar days elapsed from the first day of design to final customer acceptance of the product (Harter et al., 2000). Product size (measured by thousand lines of source code in a product) is a significant factor in cycle time (e.g., Harter et al. 2000). It is natural for larger projects to take longer development time. Using raw values of cycle time in data analysis would introduce unwanted variations among projects. Therefore, in this paper, the values of cycle time are normalized by product size to eliminate the size effect.
**Development effort**

Development effort is another dimension of project performance. In this study, the total number of person months logged by the development team from initial design through final product acceptance testing constitutes the development effort. Similar to cycle time, development effort is highly dependent on product size. Several studies have shown that thousand lines of source code is a strong predictor of development effort (e.g., Albrecht & Gaffney, 1983). To compare data from multiple projects, we normalize the values of effort by product size.

**Product quality**

Software quality is the third dimension of project performance. Here, it is measured as the number of lines of source code in the product divided by the sum of defects found in system and acceptance testing (Harter et al. 2000). This measure is the inverse of the defect density used in many previous quality studies (e.g., Fenton and Pfleeger 1997). This paper adopts the inversed defect density because it offers a more intuitive understanding of the quality values: higher values mean better performance.

**Control variables**

Past research indicated that process maturity, product size, product design complexity and ambiguity of user requirements have significant impacts on cycle time, development effort and product quality (e.g., Harter et al. 2000). Therefore, they were included as control variables in the analysis. Process Maturity is measured by the SEI’s CMM level of maturity. Product Size is measured by KLOC (thousand lines of source code). Product Design Complexity captures the complexity of decision paths and structures in the software product. User requirements ambiguity reflects how clear user requirements specifications are. Both design complexity and
of user requirements ambiguity are assessed by software developers and quantified on a scale of 1 to 5. A rating of 5 indicates the highest level of product design complexity or the highest degree of ambiguity in user requirements specification.

**Regression models**

We developed six research models to test the impacts of schedule or budget pressure on cycle time, effort and quality of software projects. Their general function forms are:

Cycle Time = \( f(\text{process-maturity, product-design-complexity, quality, schedule-pressure}) \) \( (a) \)

Effort = \( f(\text{process-maturity, product-design-complexity, quality, schedule-pressure}) \) \( (b) \)

Quality = \( f(\text{process-maturity, size, user-requirements-ambiguity, schedule-pressure}) \) \( (c) \)

Cycle Time = \( f(\text{process-maturity, product-design-complexity, quality, budget-pressure}) \) \( (d) \)

Effort = \( f(\text{process-maturity, product-design-complexity, quality, budget-pressure}) \) \( (e) \)

Quality = \( f(\text{process-maturity, size, user-requirements-ambiguity, budget-pressure}) \) \( (f) \)

In models about cycle time and effort (a, b, d and e), quality is included as an independent variable. This allows us to test whether reduced cycle time or effort is achieved at the expense of lower quality. Conventionally, it was believed that less development time or effort was related to lower quality. However, Harter et al. (2000) found that improvements in process maturity could reduce cycle time and effort, and enhance quality at the same time. In this study, we attempt to understand how the relationship between cycle time, effort and quality bears out under schedule or budget pressure.
Hypotheses
As discussed earlier, the mechanism of the pressure effect indicates that pressure has a U-shaped or inverse U-shaped relationship with performance. The U-shaped view can unify the seemingly inconsistent findings in the literature. With the U-shaped view as the rationale, we expected the following answers to our research questions:

**H1:** Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software development cycle time, with the actual cycle time increasing for projects whose pressure is either very high or very low.

**H2:** Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software development effort, with the actual effort increasing for projects whose pressure is either very high or very low.

**H3:** Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software quality, with quality decreasing for projects whose pressure is either very high or very low.

**H4:** Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software development cycle time, with the actual cycle time increasing for projects whose pressure is either very high or very low.
H5: Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software development effort, with the actual effort increasing for projects whose pressure is either very high or very low.

H6: Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software quality, with quality decreasing for projects whose pressure is either very high or very low.

5. RESEARCH METHODOLOGY

Data Collection

To test the hypotheses, we collected data on software projects performed between 1984 and 2004 from a $25 billion/year international technology firm. The company contracts to commercial, international and government clients.

Process improvement data were collected from government auditors and personnel in external divisions. These independent groups used the SEI’s CMM (Paulk, et al. 1995) to assess the maturity of the IT firm’s software development and supporting activities.

All the other data were collected by the IT firm and were audited by the clients to ensure accuracy and accountability. Particularly, cycle time data were retrieved from the Artemis© scheduling system. Effort data were tracked by the corporate time reporting system and summarized by software development projects. Software error data were from a Configuration Management (CM) database that contains errors identified during the IT firm’s system level test and during the customer’s acceptance test. Information related to the estimated, budgeted, and
actual duration and cost of software development was manually coded from the electronic and paper files maintained by the firm.

The IT firm provided an ideal site for this research because its estimation method is immunized to the “padding” effect. In software industry, development teams often extend their “rational” estimates of cycle time or cost to counteract the high levels of pressure (Yourdon, 1997). The magnitude of this padding effect varies across project teams and is hard to assess. As a result, many research findings were tampered by the confounding effect of “padding.” At our research site, development teams estimated design complexity based on user requirement specification documents. The scores of design complexity were submitted to the Software Productivity Quality and Reliability (SPQR20©) methodology for schedule and budget projection. The SPQR20© prevents arbitrary distortion of schedule or budget estimation. Therefore, our data are free of the padding effect.

Meanwhile, to prevent estimation inaccuracy introduced by SPQR, development teams used historical data to calibrate schedule and budget projection from SPQR. At the research sites, SPQR tended to under-estimate the productivity of development teams, and thus over-estimate schedule and budget for a project. To reach proper estimates, teams usually reduced the schedule and budget projection from SPQR by an adjustment factor. The adjustment factors were calculated according to historical data. The downward adjustment of SPQR estimates ensured that the pressure values in this analysis were not confounded by inaccuracy from estimation tools.

We found 21 projects with suitable data for the study of schedule pressure and 22 for budget pressure. Fourteen projects were present in both data sets. On average, the schedule pressure projects have 132,278 lines of source code (LOC), 810 days of development cycle time,
218 man-month effort and one defect in every 841 lines of code. Table 1 shows the summary of
the schedule pressure data.

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Insert Table 1 about here

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The budget pressure projects have an average of 98,938 LOC, 478 days of development cycle
time, 186 man-month effort and one defect in every 1,162 LOC. Table 2 displays the summary
of the budget pressure data.

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6. ANALYSIS AND RESULTS

To test the existence of the U-shaped pressure-performance relationship, we included
quadratic terms of schedule or budget pressure as independent variables in the statistical models.
This method has been proved effective by previous studies (e.g., Banker and Kemerer, 1989).
The specific regression models for schedule pressure analysis are:

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Normalized \ Cycle \ Time = \beta_0 + \beta_1 (process-maturity) + \beta_2 (product-design-complexity) + \\
\beta_3 (quality) + \beta_4 (schedule-pressure) + \beta_5 (schedule-pressure)^2 \quad (1)
\]

\[
Normalized \ Effort = \beta_0 + \beta_1 (process-maturity) + \beta_2 (product-design-complexity) + \beta_3 \\
(quality) + \beta_4 (schedule-pressure) + \beta_5 (schedule-pressure)^2 \quad (2)
\]
Quality = $\beta_0 + \beta_1 \text{(process-maturity)} + \beta_2 \text{(size)} + \beta_3 \text{(requirements-ambiguity)}$

+ $\beta_4 \text{(schedule-pressure)} + \beta_5 \text{(schedule-pressure)}^2$  \hspace{1cm} (3)

The statistical models for budget pressure analysis are:

$\text{Normalized Cycle Time} = \beta_0 + \beta_1 \text{(process-maturity)} + \beta_2 \text{(product-design-complexity)} +$

$\beta_3 \text{(quality)} + \beta_4 \text{(budget-pressure)} + \beta_5 \text{(budget-pressure)}^2$  \hspace{1cm} (4)

$\text{Normalized Effort} = \beta_0 + \beta_1 \text{(process-maturity)} + \beta_2 \text{(product-design-complexity)} + \beta_3$

$\text{(quality)} + \beta_4 \text{(budget-pressure)} + \beta_5 \text{(budget-pressure)}^2$  \hspace{1cm} (5)

$\text{Quality} = \beta_0 + \beta_1 \text{(process-maturity)} + \beta_2 \text{(size)} + \beta_3 \text{(requirements-ambiguity)}$

+ $\beta_4 \text{(budget pressure)} + \beta_5 \text{(budget pressure)}^2$  \hspace{1cm} (6)

The models were initially tested with ordinary least squares (OLS). However, because data in this study are all from the same company, it may be possible that the error terms are correlated as a result of some common effect. Therefore, we also estimated the seemingly unrelated regression (SURE) parameters using a feasible generalized least squares (FGLS). Table 3 displays both OLS and SURE estimates for the schedule pressure models (Eq 1 to Eq3). Table 4 summarizes the OLS and SURE estimates for the budget pressure models (Eq4 to Eq6).
Generally speaking, OLS and SURE produced consistent results. Both OLS and SURE found that cycle time was affected by the quadratic schedule pressure ($p<.05$) and the quadratic budget pressure ($p<.05$). Both indicated that effort was only affected by the quadratic budget pressure ($p<.05$) but not the quadratic schedule pressure ($p>0.1$). Meanwhile, budget pressure had a significant impact on software quality ($p<.05$) whereas schedule pressure did not affect quality ($p>0.1$). Since SURE accounted for the potential correlation among disturbances in our models and produced consistent results with OLS, we used the SURE estimates for the interpretation of our results.

In the cycle time equation of the schedule pressure models (Eq 1), we found that schedule pressure had a significant impact on software development cycle time, with the actual cycle time increasing for projects whose schedule pressure was either very high or very low ($\beta=34.68$, $p=0.002$). The positive coefficient of the quadratic term means that the actual cycle time rises at an increasing rate when schedule pressure gets farther away from the optimal point. This result supports our first hypothesis:
H1: Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software development cycle time, with the actual cycle time increasing for projects whose pressure is either very high or very low.

By differentiating cycle time with respect to schedule pressure, we obtained 0.26 as the optimal schedule pressure value. That is, the shortest cycle time occurred when management reduced the team estimated cycle time by 26%. Figure 2 visualizes the U-shaped relationship between schedule pressure and development cycle time.

While schedule pressure had a significant impact on development cycle time, we did not find it affect development effort ($p > 0.1$). We have to reject the second hypothesis:

H2: Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software development effort, with the actual effort increasing for projects whose pressure is either very high or very low.

Rejection of H2 suggests that schedule pressure has a stronger impact on time related measures (e.g., development cycle time) than on cost related variables (e.g., development effort). An intuitive explanation for this result is implied by the famous Brooks’s Law (Brooks, 1975). Brooks’s Law indicates that when there is schedule pressure, the natural reaction is to attempt to
reduce the expected completion date by adding extra staff (Jeffery, 1987). In other words, while schedule pressure reduces cycle time, it tends to increase the number of staff for a project. The combination of increased staff and decreased cycle time usually leads to seemingly stable man-month values of effort. Therefore, we do not observe a significant U-shaped relationship between schedule pressure and effort.

The results of the budget pressure models indicated that budget pressure had a U-shaped relation with both development cycle time and development effort. Specifically, we found a positive and significant coefficient ($\beta=3903, p=0.018$) for the quadratic term in the cycle time equation (Eq4). Similarly, the coefficient for the quadratic term in the effort equation (Eq5) was positive and statistically significant ($\beta=765.68, p=0.014$). Comparing the significance values of the quadratic budget pressure terms ($p=0.014$ vs. $p=0.018$), we see that budget pressure tends to have a stronger impact on cost related measures (e.g., effort) than on time related variables (e.g., cycle time).

The positive coefficients of the quadratic terms indicate that when budget pressure gets farther away from the optimal value, the actual cycle time and effort will increase at an increasing rate. These results support our fourth and fifth hypotheses:

**H4: Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software development cycle time, with the actual cycle time increasing for projects whose pressure is either very high or very low.**
H5: Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software development effort, with the actual effort increasing for projects whose pressure is either very high or very low.

By differentiating cycle time and effort with respect to budget pressure, we obtained 0.20 as the optimal pressure value for both cycle time and effort. This implies that when management reduced the team estimated budget by 20%, the project took the least cycle time and effort. Figure 3a and 3b illustrate the U-shaped functions between budget pressure and cycle time and effort respectively.

In the quality equation of the schedule pressure models (Eq 3), we did not find that the coefficients of the linear and quadratic pressure terms were significantly different from zero. It indicates that schedule pressure did not substantially affect quality of the software products. Thus, our third hypothesis is rejected:
H3: Schedule pressure created by the discrepancy between the ideal estimated time and a management constrained deadline has a significant impact on software quality, with quality decreasing for projects whose pressure is either very high or very low.

This result may be counter-intuitive, since we often assume that people make more mistakes under greater pressure. Boehm (1981) pointed out that when schedule pressure is low, software management tend to allocate more time and effort to the initial planning. Meanwhile, Abdel-Hamid (1999: 533) argued, “initial project plans do not necessarily constitute the best course of action to take during the project’s life cycle.” In other words, under low schedule pressure, the increased time and effort are often unrelated to quality improvement. On the other hand, when schedule pressure is high, developers deliberately spend more time and effort to maintain quality rather than meet deadlines (Austin, 2001).

Although software quality is not affected by schedule pressure, it is significantly associated with budget pressure. We found that both the linear and quadratic pressure terms in the quality equation (Eq6) were statistically significant ($p<0.05$). However, the coefficient of the quadratic pressure term is positive, which indicates a convex rather than concave function between budget pressure and quality. The statistical results partially support our sixth hypothesis:

H6: Budget pressure created by the discrepancy between the ideal estimated cost and a management constrained budget has a significant impact on software quality, with quality decreasing for projects whose pressure is either very high or very low.
The convexity of the budget pressure effect on quality is contrary to our expectation. It suggests that under budget pressure, there is a trade-off between reduced cycle time or effort and software quality. Shorter cycle time and less effort are achieved at the expense of quality. Under a moderate level of budget pressure, the detrimental effect of reduced cycle time and effort is stronger than the positive effect of pressure on quality.

Overall, we see that budget pressure has significant U-shaped relationships with development cycle time and effort. In contrast, schedule pressure affects only cycle time, not development effort. Budget pressure is more likely to influence cost related factors, such as development effort, whereas schedule pressure has stronger effects on time related variables, such as development cycle time. In addition, budget pressure influences software quality while schedule pressure does not.

The analysis results strengthened our confidence in the mechanism of the pressure effect. As indicated by the behavioral perspectives, there were positive relationships between schedule or budget pressure and project performance under low levels of pressure (less than 26% schedule pressure or less than 20% budget pressure). This implies that the positive effects of pressure (task goals, excitement of a task, work time and work speed) dominated the pressure-performance relationship when pressure levels were low. With the increasing of schedule or budget pressure, the negative impacts of pressure (task difficulty, stress, fatigue and negligence) gained strength and eventually offset the positive effects. Thus, we saw negative relationships between schedule or budget pressure and project performance when pressure levels were high (more than 26% schedule pressure or more than 20% budget pressure). In general, results of this paper confirmed the U-shaped views implied by the mechanism of the pressure effect.
When interpreting the above results, we were aware of the relatively small sample size available to this study. Sample size is a parameter defining the power of any statistical test. Low statistical power can prevent researchers from identifying an existing effect. In MIS studies, the average level of statistical power is relatively low (Baroudi & Orlikowski 1989). A major reason is that it is very difficult to collect large amount of empirical data. This study, like many other MIS studies, is constrained by the availability of data points. However, with such a small data set, we were still able to find statistically significant effects of schedule and budget pressure in the research models. This indicates that the effect size of schedule or budget pressure is very strong. Therefore, we believe our small sample size in effect strengthens the data analysis results.

7. CONCLUSION AND IMPLICATION

In this paper, we introduced the relevant behavioral perspective to examine the impacts of schedule and budget pressures on project performance. The behavioral perspectives enabled us to explore the mechanism behind the pressure effects. The mechanism in turn provides a reasonable framework to reconcile the seemingly conflicting views in the MIS literature.

In operation, we developed intuitive and effective metrics of schedule and budget pressure in the context of software development management. These metrics can be generalized to other studies about the impact of management pressure. Meanwhile, by controlling for several critical confounding variables, our data analysis produced interesting and reliable findings.

To practitioners, the theoretical development of this paper helps them understand the subtle psychological and behavioral forces underlying the pressure effect. To induce the optimal performance, managers can fortify the positive forces (task goals, excitement of a task, work
time and work speed) as well as suppress the negative influences (task difficulty, stress, fatigue and negligence).

The empirical findings of this paper have valuable implications. First, adding schedule pressure to software development teams can shorten the actual development time. Managers can increase the productivity of their teams by imposing tighter schedules. However, there is a limit to this beneficial effect of pressure. When management cuts too much time off a team estimated schedule (more than 26%), developers will “burn out” and end up taking more time to finish their work.

Second, when schedule pressure reduces cycle time, it does not affect software quality. To software project managers, balancing development speed and quality is an important issue. Our results imply that project managers can maintain quality while applying schedule pressure to reduce project duration. In other words, under the optimal level of pressure, software development teams can finish projects in shorter time without compromising quality.

Third, applying budget pressure to software development teams can not only shorten development cycle time but also lower development effort. The reduced cycle time under budget pressure is not paid off by an increased work force. On the contrary, with a properly tightened budget, software management can save time and manpower at the same time. However, there is a limit to this positive effect. If management gives a team too much budget pressure (more than 20%), development time and effort will rise.

Finally, budget pressure affects software quality. When leveraging the positive impacts of budget pressure, managers have to consider its potential harmful effect on quality. Effective budget setting strategies should include quality control measures to offset the negative impact of budget pressure.
In the highly competitive software engineering industry, companies are looking for ways to make software production more efficient. This study can help project managers understand the relationship between pressure and project performance. The analysis results offer quantitative yardsticks for effective negotiation strategies and deadline and budget setting policies, which ultimately add to the competitive advantage of an IT company.
REFERENCE


33. Yerkes, R.M., and Dodson, J.D. The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative and Neurological Psychology*, 18, 1908, 459-482.

TABLE 1

Description of the Schedule Data

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### TABLE 3
Parameter Estimates of the Schedule Pressure Models

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FIGURE 1
The mechanism of pressure effects

Schedule or budget pressure

Task difficulty
Stress
Fatigue
Negligence

Task goals
Excitement
Work time
Work speed

Performance:
Cycle time, effort and quality

+ +
-

+ +
FIGURE 2
The U-shaped function between schedule pressure and cycle time

Note: the cycle time values in this figure are calculated with average values of product design complexity, quality and process maturity of the schedule pressure data.
FIGURE 3A
The U-shaped function between budget pressure and cycle time

Note: the cycle time values in this figure are calculated with average values of product design complexity, quality and process maturity of the budget pressure data.
FIGURE 3B

The U-shaped function between budget pressure and development effort

Note: the effort values in this figure are calculated with average values of product design complexity, quality and process maturity of the budget pressure data.