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Managing Risk in New Product Development

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Abstract

Programs at a medium-size electronics design and manufacturing company are conducted under a development policy of a stage-gate format. By this policy, a document is created by the multifunctional development team at each milestone (or gate), reviewed by management for approval, and entered into an archive. Information to be included in each milestone document is described by the policy, making the archive a source of program information thought to be relatively uniform.

Research was performed to investigate the risk management practices under the development policy, to determine relationships between schedule overruns and each of five different identified risks areas: risk identified at project start; unforeseen risk; amount of new content; changes in product requirements; and disagreement over schedule.

Content and non-parametric analysis of sixteen completed programs, using the archived milestone documents and interviews with program managers was conducted. Non-parametric techniques were applied to examine the relationships between schedule slips and the five areas related to risk management.

Background

The projects considered in this analysis are for the purpose of designing new products to be manufactured, marketed and sold by the company. Project teams have representation from marketing, hardware and software development engineering, reliability and safety engineering, manufacturing, service, customer documentation, procurement, and new product introduction services. The company typically designs products that are technically advanced, in volumes that are much lower than those of consumer products and meet very high environmental compatibility standards. Technical invention is frequently required. The company operates in compliance with ISO 9001.

All projects considered in this analysis were conducted under a new product policy (NPP), which institutes a stage-and-gate approach with formal documentation required at each gate, or milestone. NPP was instituted at the company to increase the level of predictability of programs by increasing the level of control and visibility. Inherent in the policy is the desire to identify and properly manage risks, mitigating them as early as possible within reason.

Of the NPP milestones, two are most significant in judging the performance of a project with respect to schedule: development plan completed (DP) and product shipment release

(PSR). The approval of the DP milestone signifies that management and the project team agree that the following have occurred:

- the risks to timely and predictable completion have been sufficiently mitigated;
- the project has been sufficiently well planned;
- the required business and market returns are expected to be met, and;
- the manpower has been committed to execute the project.

The approval of the PSR milestone signifies that;

- all activities planned at DP have been completed;
- the product as designed has been proven to meet the requirements, and;
- the company has proven the ability to sustain shipments to customers.

DP is generally considered as the emotional "start" of the project, while PSR is typically the emotional "end" of the project.

The NPP defines a program manager who is responsible for pulling together all the information at each milestone and authoring the document that represents the input from all the functional areas affected by the project. Each functional area provides a "core team" member, who is responsible for providing all necessary linkage between the project and their function for the duration. In this arrangement, the core team provides the content of the milestone documents, the program manager coordinates and writes the document, and a general manager or vice president approves the milestone. In general the policy gives approval authority for small programs (less than $25,000) to general managers, while a vice president approves larger programs. The policy gives the vice president authority to make exceptions as appropriate.

When judging how well a program performed with respect to schedule, a dominant measure within the company is how close the project reached PSR in relation to the plan set forth at DP.

Problem Statement

In simple terms, projects sometimes do not reach PSR on the projected date. This has a variety of detrimental effects that will not be explored here, but the reader can easily the company's desire to avoid schedule slips because of:

- financial impact on the business due to cost overruns and delayed revenue streams;
- missed opportunities on other projects from resources being delayed;
- frustration and confusion in the sales channel;
- degradation of the company reputation from missed customer commitments
- stress on team members from trying to make up time.

Among the many possible causes of schedule slip, the five probable causes listed below were investigated:

- amount of new content in the project;
- risks that were not foreseen at DP;
- disagreement between implementers and managers on schedule;
- great amounts of identified risk at DP;
- changes in product requirements after DP.

New Content. Projects with appreciable new content are those where successful completion of the project requires the execution or invention of something the company has not delivered before. This could include the development of a new component, circuit or algorithm, the creation of new distribution and sales channels, or the mastery of new manufacturing techniques.

Unforeseen Risk. Risks that were not foreseen at DP when the project plans and resource commitments are finalized infers that the project plan and approach is put together with insufficient thought. It could also mean that the project was subjected to unanticipated changes in the environment. Examples could include a reorganization of the division with shifting priorities, changes in engineering tool sets, and insufficient analysis of technical approaches.

Schedule Discord. Disagreement between implementers and managers with regard to schedule is a classic struggle. This category refers to the situation where the schedule formally presented in the DP documentation does not reflect what the implementation team regards as realistic. The team may regard the schedule as possible, but not probable. The NPP assumes that the project team is committed to delivering the project to schedule, whereas the team may regard this schedule as a guideline or target.

Identified Risk. This category refers to the condition where a program may be well planned and adequately staffed, but the known risk at DP is considered to be capable to significantly altering the program. In the simplest case, one area of significant invention or innovation may be scheduled, which is difficult to accurately plan. A more complex case is when many risks are expected to be managed concurrently.

Requirements Change. Change in product requirements after DP refers to the fact that a plan, approach, schedule, and staffing commitment have been agreed upon at DP in relation to the requirements for the product. Changes in the requirements can translate to a change in scope of the project, causing the need for more man-hours to be expended. There are cases where the additional man-hours are supplied in the form of additional people, but more usually the man-hours increase through more time from the existing team. Example of requirements that could change are cost, electrical performance, size, reliability, and feature set.

Approach:

The intended approach at the outset of this research was to use data supplied in the archived milestone documents from a set of projects. The uniformity of the milestone documents across projects was expected to minimize bias in the study. However, an inspection of milestone documents for approximately twenty projects showed that while precise information could be gained as to the planned vs. actual project duration, the milestone documents contained data on just two of the five probable causes: identified risk and new content. To gather data on unforeseen risk, schedule discord and requirements change, alternative sources were needed. Some programs were found to have conducted post-project reviews, but these were not uniform between the programs. Therefore, interviews with program managers were conducted to augment the milestone documents.

Consideration was given to developing a parametric questionnaire, but the short timeframe of the research project made it difficult to validate such an approach. Given the data and time available, non-parametric techniques were chosen. Sixteen projects were selected and classified by performance to schedule. Those achieving PSR within 3 months of the date projected at DP were considered to have "small" schedule slips while those achieving PSR 3 months or more beyond the projected date were considered to have "large" slips. The population of projects was evenly divided between "small" and "large". Some thought was given to classifying projects by schedule slip as a percentage of total forecasted project duration, with the threshold arbitrarily set at 20%. This approach was discarded for two reasons. First, the detrimental effects of schedule slip do not vary as a function of forecasted project duration. A product making it to market a month late means an additional month's worth of investment and a month's worth of lost market opportunity regardless of how long the product has been under development. The same can be said for the cost of lost goodwill and disruption to the distribution channel. Second, the projects chosen would have been classified into the same "small" and "large" categories either way. The absolute measure was therefore chosen for simplicity.

Next, each project was classified with relation to the five potential causes of schedule slip. The following table summarizes the criteria:

Potential Cause	CLASSIFICATION LOW	HIGH
New Content	Company has done this before	New to company or to the world
Unforeseen Risk	Events occurred during project as anticipated, or occurred without seriously affecting the project	Events happened which were not anticipated or considered to be high risk, and caused a change to the project
Schedule Discord	Implementers and program management substantially agreed on schedule at DP	DP was approved with more than 3 months' disagreement on projected project duration
Identified Risk	At DP, no risks were known that could cause the project to abort.	At DP, at least one "show stopper" was known, to be conquered by PSR
Requirements Change	No changes occurred after DP of a sufficient nature to cause confusion or retrenchment in the project	After DP a change in specification, delivery date or other change caused confusion or retrenchment in the project

Interviews were conducted via email with the program managers of the projects to have them classify the projects against each of the five potential causes of schedule slip. Refer to Appendix I for a summary of the data for the sixteen projects. Refer to Appendix III for the questionnaire sent to program managers.

Results:

The same Fisher Exact Probability Test with Tocher's modification was performed for each probable cause, comparing against the distribution of schedule slip. The summary of the probabilities is shown below, where p_H is the Fisher Exact Probability, and p_T is the Fisher Probability with Tocher's modification. In cases where the two number are identical, the observed data already represents the most extreme possible case. All cases are against a significance level of $\alpha = 0.1$ for a one-tailed probability.

Probable Cause	p_F	p_T	Significant
Degree of New Content	**0.1371**	**0.1573**	**No**
Unforeseen Risk	**0.0385**	**0.0385**	**Yes**
Schedule Disagreement	**0.1000**	**0.1000**	**Yes**
Identified Risk	**0.1282**	**0.1410**	**No**
Requirements Change	**0.2333**	**0.2333**	**No**

Degree of New Content. The probabilities with and without Tocher's modification were found to be greater than α, therefore H_0 must be accepted. Schedule slip between DP and PSR is indicated to be independent of the degree of new content in a project. This would suggest that programs with significant new content are recognized by project planners to require sufficient time for mastery of the new area. Projects with differing types of new content were included in the study, but primarily the new areas were concerned with the design of new technology.

Looking more closely at the five projects fitting into the matrix under large schedule slip and high degree of new content shows that for all these projects the significant new technology content was in hardware development. The two projects demonstrating small schedule slips and high degree of new content contained significant software development efforts and minor hardware efforts. The intuitive explanation for the difference lies in the fact that breakthroughs tend to be paced by the engineers' ability to iterate towards a solution, which tends to have much longer cycle times in the hardware domain.

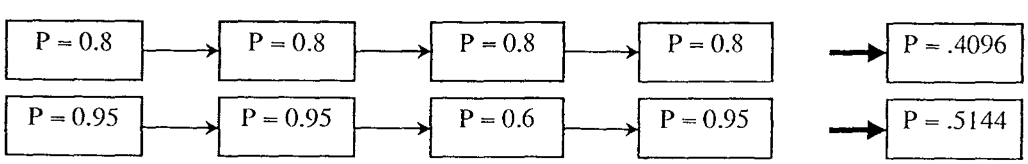
Unforeseen Risk. The probability was found to be much less than α, therefore H_0 must be rejected in favor of H_1. Schedule slip between DP and PSR is indicated as significantly related to the degree of unforeseen risk in this population. This relationship is intuitively obvious. Of course, problems that arise during the course of a project that were unplanned will cause additional effort to be expended. In most cases, additional resources are not available to be added, so additional time with current resources is required.

Examining the four projects, which demonstrated large schedule slips and high unforeseen risk, the risk type is found to be varied. One of the projects encountered large technical risks past DP, a second encountered the need to ship early products to customers, while the other two projects encountered significant reorganization of the division. In the latter case, the result was upheaval in tools, systems and available staff. In the first case, reflection on the project showed that more thorough risk identification and reduction prior to DP was possible but was not integrated into project plans. In the last three cases, it was impossible to foresee the changes. These observations tend to reinforce the notion of keeping a stable environment and targets around a project team yielding more predictable results.

Schedule Disagreement. The probability was found to be equal to α, therefore *Ho* must be rejected in favor of H_1. Schedule slip between DP and PSR appears to be related to the presence of schedule disagreement at the 0.10 confidence interval level. What the data did not indicate was which schedule prediction, that of the implementers or that of the managers, proved more accurate. A variety of prototypical situations have occurred on projects within the company, including: management- or marketing-imposed deadlines; reluctance on the part of implementers to commit to schedule; and generally poor planning. At least one of the projects that fell into the "high disagreement" and "large schedule slip" categories, all three situations were known to exist.

Another variation of the schedule disagreement theme which has been witnessed in the company occurs when management or marketing imposes the schedule and would be satisfied with "minimum acceptable" performance, while engineering believes that the performance level required to meet the market needs is considerably above the minimum. At least one of the projects suffered from this situation. On this project, this protracted disagreement caused changes in requirements over the course of the project in addition to the schedule dispute.

Identified Risk. The probability was found to be greater than α, therefore *Ho* must be accepted, although at $p = 0.140$ was only slightly beyond the significance level of 0.10. Assuming some relationship could exist between schedule slip and large amounts of identified risk, the notion of projects with risk spread across a program being less probable to meet schedule dates than a program with concentrated risk is suggested[1]. A program with a relatively large number of identified risks relates to the situation in the top of the following figure. Maintaining a moderate degree of probable success for events that lead one to another combines to yield a relatively low probability of overall success. The second situation, depicted in the lower figure is that of a program with risk concentrated in one area combined with related, low-risk tasks. The latter approach yields a noticeably higher probability of overall success.



Of the four programs having significant risk and suffering large schedule slips, all were characterized with significant risk in multiple areas of hardware. Given the fact that refinement of the hardware design involves longer logistical loops and more organizations than software, the suggestion could be made for the containment of iterations within a program as a way to increase the independence between identified risk and schedule slip.

Another examination of the relationship between slip and identified risk is on the basis of project management excellence. How well a project is managed could be described in terms of reducing risk early in the project rather than carrying risk forward, a solid planning sequence in place, and accurate assessments of task duration and required skills. One project that had high identified risk but exhibited no schedule slip was well executed in these terms. Three of the projects having high identified risk and were thought to be programs of relatively short duration (nine months or less) were later found to be affected by risk reduction occurring too late. At least two of the projects were also found to contain inaccurate assessments of task duration as well. These projects contained significant new content as well, which made them more difficult to plan. The general suggestion here is that programs with high degree of identified risk require more care in planning and execution.

Requirements Change. The probability was found to be much greater than α, therefore *Ho* must be accepted. Schedule slip between DP and PSR is indicated to be independent of change in requirements. In looking at the two projects which had "high" degrees of requirements change after DP and "large" schedule slips, requirements were not well defined at DP. Rather than the requirements being substantially redefined after DP, these project continued in the same basic direction with several features "roughed in", with further refinement occurring in the course of the project. Further interviews with project team members indicate that although sometimes frustrating to be executing against fluid requirements, enough definition and a decision-making process was available to prevent the project from stalling. The data shows six other projects that encountered large schedule slips without significant change in requirements.

The independence between schedule and changing requirements was unexpected. Conventional wisdom suggests that projects with requirements that are not well understood and communicated leads to an inability to make effective tradeoffs at all levels of the project, and causes increasingly larger amounts of work to be redone the later these changes are made[1]. The independence found in the data suggests that the projects considered in this analysis were generally effective at making tradeoffs even in the face of fluid requirements, and that the projects were able to accommodate for any rework necessary.

Conclusions:

Of the five proposed causes of schedule slip among a heterogeneous population of sixteen projects, two were found to have significant relationship to schedule slips of three months or more. Unforeseen risk and schedule disagreement are relevant factors at the 0.10 significance level. Identified risk is found to be marginally unrelated to schedule slip for the population analyzed, with particular examples noted to be highly related. Degree of new content and change in requirements was found to be unrelated to schedule slip in the population studied.

These results suggest that the projects are conducted in an environment where new content is sufficiently well characterized for impact on a project, and that project teams possess enough flexibility to accommodate change in requirements. Projects were included which contained significant new content and requirements change, and the results would support the notion that these factors were correctly managed.

The results also infer that when risk can be identified, project teams manage it sufficiently well. There are examples included where this is known not to be the case, but as a population, the projects were found to be effective at dealing with identified risk.

The results correlating unforeseen risk to schedule slip suggest that improvements could be made in the ability to identify risk. Given that identified risk appears to be properly managed, efforts to improve risk assessment techniques should prove useful. This applies not only to technical risks, but also to organizational risk. Recall that two of the projects presented with unforeseen risk were the subjects of significant organizational change. The effect of changing the tools, methods and staffing in an unexpected manner appears have a high impact on projects in this environment.

The results correlating schedule disagreement to schedule slip are perhaps the least surprising. On two of the programs studied, the project leaders and implementers expressed informal disagreement with the stated schedule and predicted a PSR date that was significantly later than management desired. The fact that the projects were approved and advanced suggests there existed serious differences in the assumptions made by the two groups (management and implementers) about what was reasonable.

Discussion:

Known weaknesses. During the process of this research some weaknesses were noted that should be identified. This first is with the data source, the milestone documentation and interviews with project leaders. As mentioned before, the milestone documents were originally thought to be uniform and would contain sufficient information from which a reasonably objective data set could be drawn. The only reliable, uniform data source available from the documentation is the dates on which milestones were projected to occur, and when they actually did occur. Looking to the milestone documents to assess each program against the five categories of potential cause for schedule slip was found to be useful in identifying only two of the categories: identified risk and new content. At the DP milestone the NPP requires the risks to be identified and accounted for in the project plan. Given the milestone document is forward-looking and is written to gain approval for moving to the next phase of the project, all DP documents accounted for these risks. The remaining categories (schedule disagreement, unforeseen risk, requirements change) do not appear in DP documents because they are either not recognized at that point in time or would be the indication of incomplete planning. These categories are of the type that arise during the execution of the project and are documented only in the detailed management documents within the project. As the next milestone approaches, thorough disclosure of these issues does little to move the project to the next phase, so little analysis (if any) is offered other than to acknowledge the issue as a cause of delay. Given the short time duration given for completion of this analysis, this led to the need to interview project team members in an abbreviated manner, and the choice of non-parametric scales.

The projects included varied in disciplines required for execution, making them sometimes quite different in nature and scope. Some were software projects only, some were hardware with minor software content, while some were considerable in both disciplines. Those that were software only were varied as well, with at least being a software program of considerable new content while others were more evolutionary in nature. Projects with major degrees of hardware content involve virtually all areas of the company, making them much more complex to plan and conduct. Projects with major hardware and software bring the additional complexity of system integration. The variety of projects translates into a varying degree of consequence of the five probable causes considered. In other words, a high degree of change in requirements will have considerably different impact on a software-oriented project than a hardware-oriented project. Both can translate to schedule slip, of course, but turning hardware involves many more organizations to be coordinated than turning software.

One bias that is expected in the milestone documentation is that of optimistic reporting. The purpose of the milestone document is to seek approval from a senior manager to cross from one phase to the next. Teams tend to focus on the positive aspect of reaching a milestone and not so much on the negative aspects of why they may be performing other than plan. As a consequence, it is unusual that a milestone document contains an objective description of cause when schedule, cost or product performance did not meet the DP plans.

The little amount of relevant literature found during searches is surprising. This becomes a weakness of the report, in that most observations made herein are not from the standpoint of comparison to published literature. The author, being an employee of the company and involved with product development there for of fifteen years, was able to provide comparisons through first-hand knowledge of conditions during the execution of projects. While this serves to provide more exposure to dynamics within projects, the objectivity of the observations is also compromised.

The final weakness of this analysis noted is the non-uniformity in how NPP has been applied to projects over time. Several of the projects included were well on the path of execution when DP occurred, which makes their apparent projected lengths considerably shorter. This fact alone could move at least two projects, and perhaps more, from the "small" slip category to the "large", while no projects would move the other direction. Projects in the most distant past were not conducted under the degree of rigor and control as more recent projects while the company as a whole mastered the discipline of using the NPP. The NPP itself has also been refined numerous times, although the milestones and phases remained largely unchanged. The outcome of the hypothesis tests is not thought to be affected by this anomaly.

Recommendations. The NPP calls for structured and uniform documentation at each milestone, but does not call for a structured debrief at project completion. One suggestion would be to add a questionnaire to the debrief, which would be used to gather all information management would like to analyze. Rating scales for a variety of different questions could be created, allowing more exacting analysis than the non-parametric techniques used here. Better information could be gathered regarding:

- content of project (HW, SW or both);
- project size;
- experience of program manager and project leaders
- type of new content
- risks identified during the project
- stability of the business during the project.

Statistical Approach:

For the purposes of this research the projects which are "on time" are regarded as being independent from those being "late", given the projects were conducted in random manner with different teams, and sometimes in different parts of the company. For analysis, the Chi-squared approach would be preferable. However the sample size available makes the expected frequencies too small to be valid. In such cases, the Fisher Exact Probability Test with Tocher's modification is recommended [2]. See appendix II for an explanation of the test.

The level of significance is selected at 0.10. Of the two most commonly used significance levels (0.10 and 0.05)[2], this is the most generous in a study where the consequence of a Type I error is minor. This choice translates into a 0.10 probability of rejecting the Null Hypothesis when it is true. For such a small and varied sample size, it could be argued that a decision point of higher level of significance could be chosen.

In each of the five analyses, the null hypothesis was for independence, with the alternative hypothesis set for positive correlation between schedule slip and the potential cause.

i. *Null Hypothesis. Ho:* "Late" and "on time" projects show equal occurrences of potential causes for schedule slip. *H1:* a greater proportion of projects that are "late" have a "high" classification in the potential cause category they are being analyzed for..
ii. *Significance Level.* Let $\alpha = .10$. N = 16.
iii. *Sampling Distribution.* The probability of the occurrence under *Ho* for each observation is given by the equation for the Fisher Test in appendix II.
iv. *Rejection Region. H1* predicts the direction of the difference, therefore the region of rejection is one-tailed. *Ho* will be rejected if the observed values differ in the predicted direction and the calculated probability under *Ho* is less than or equal to α.

Comparison to Literature:

A majority of literature found when searching for articles on risk management in product development using a stage-gate process pertained either to discussions on phase-gate processes or the management of market risk. No articles were found that attempted to correlate risks with project performance. A majority of articles turning up from the search pertained to risk management in the construction industry, and were found to be irrelevant to this analysis. Many of the articles found discussing risk spoke heuristically about the deleterious effect of risk on projects or models, but did not strive to speak to the cause and effect relationship between specific types of risks and projects.

In *Revolutionizing Product Development*, Wheelwright and Clark describe the solution to keeping programs on track as solved by downstream competence and flexibility. The most applicable idea offered is from Chapter 11, Learning from Development Projects. The concept of a Project Audit as a framework for learning for a particular organization seems plausible as a method of causing the correct observations to be made with respect to risk management while the project is still fresh in the minds of the team. This is akin to an activity that sometimes occurs at the completion of NPP projects, the post-mortem. The Project Audit as a required element of process might serve to enhance the value of the milestone document archive for learning and analysis purposes. [3]

Smith and Reinertsen in *Developing Products in Half the Time* offer by far the most relevant body of literature to this analysis. Chapter 12 of this text is devoted to managing risk, Chapter 4 on incremental innovation, and Chapter 5 on the importance of defining specifications. It is pointed out that keeping risk outside the actual development process is favorable, which corresponds to the probable causes of degree of identified risk and degree of new content studied here. The concepts of practical experimentation to model risk areas and creating contingency plans are also explored. [1]

Rosenau, in speaking on achieving faster product development, emphasizes the importance of clearly defined development phases, and clearly defined goals, specifications and scheduling. His article shares the results of a conjoint analysis he performed which indicate that the importance of shared goals, reducing distractions, avoiding changing specifications, and effective scheduling techniques have the greatest impact on fast time-to-market.[4] The population studied here did not show the same sensitivity to requirements change but did show impact when scheduling was done inappropriately.

Griffin in her research presents a methodology for establishing a baseline for cycle time measurement, against which improvements and comparisons can be made. In her article, she recommends quantifying the amount of change across product generations and complexity, as well as the formality of the process.[5] The relevant linkage between her findings and those from this population lies in the notion that the amount of change across product generations correlates to the introduction of unforeseen risk, which did have an impact on the population studied. The viewpoint expressed in her article tends to assume these product development activities are evolutionary in nature.

Swink, Sadvig and Mabert describe working with technical risk under concurrent engineering approaches. They point out that high degrees of innovation, complexity or technical risk tend to decrease the amount of concurrency in those high-risk areas until the risks are mitigated. They suggest that this leaves parts of the organization in a position of being somewhat excluded during concurrency unless specific efforts are taken.[6] The NPP approach utilized in this company tends to minimize the exclusion the authors point to. The findings of this study tend to suggest that effective concurrent engineering is occurring when the risks can be identified.

Cooper introduces an adaptation of the stage-gate process, which adds four dimensions of change to the traditional stage-gate approach: fluidity; fuzzy gates; focused; and flexible. The concept is simply that some phases can start before their official proceeding gate is cleared, as long as the people involved can remain focused and the overall maturity of the organization can ensure this behavior does not cause the project to experience undue risk. Cooper warns that this should be done only with recognition of the risks involved.[7] The NPP approach in the company studied allows for fuzzy gates and fluidity Cooper refers to, as long as the activities can be justified, and this type of behavior is regularly practiced. In one of the projects studied, the milestones were quite compromised for the sake of fast time-to-market, and the unforeseen risks incurred were those that ultimately caused the cancellation of the project.

Kostoff identifies seven risk categories in research programs, which is helpful in starting to build a classification methodology to quantify product development risks. His categories are: large extrapolations; difficult data gathering; additional complexities required; high precision required; breakthroughs required; theories insufficient; and record of past difficulties.[8] Although these are presented to categorize research projects, they apply well to those situations where high degrees of new content apply in the projects studied, and could be the basis for helping turn unforeseen risks into identified risks.

Hise and Groth offer one of the better risk evaluation schemas, although in their application the risks described are external and market risks rather than the technical and execution risks that were the subject of this study. It is offered here as a possible measurement and tracking approach.

Ali, Krapfel and LaBahn offer research that correlates short cycle times and faster break-even times with keeping the technical content of the product simple. They conclude that greater degrees of required innovation and higher level of technical complexity delay the product's arrival in the marketplace.[10] Their observations have only to do with cycle time, and not with schedule slip. Indeed, the programs studied here to tend to agree with the assertion from Ali, et.al.: more complex projects take longer.

Cooper and Kleinschmidt studied 103 new product development efforts in the chemical industry, and offer six drivers of product timeliness: project organization; up-front homework; strong market orientation; technical proficiency; market attractiveness; product definition; and launch quality.[11] While there may be some congruence between their findings and those in this study, it is difficult to ascertain the relationship. One could assume that up-front homework could contain the categories of this study that pertain to indentified risk and schedule discord, or that product definition pertains to requirements change. It is unclear from the article how narrowly defined their categories are.

The final relevant article found was related to the construction industry, but offers a simple methodology of quantifying risk using a hierarchical process.[12] The study done here suggests that the company is effective at scheduling and planning once the risks are identified, but perhaps the approach offered by Mustafa and Al-Bahar could be considered as a uniform method of expressing those risks, their strengths and relationships.

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Appendix I

The data table below contains the classification, by project, for schedule slippage and each of the five probable causes analyzed against slippage.

Project	Schedule Slip	New Content	Unforeseen Risk	Schedule Disagreement	Identified Risk	Requirements Change
1	Small	High	Low	Low	Low	Low
2	Small	Low	Low	Low	Low	Low
3	Small	High	Low	Low	Low	Low
4	Large	High	Low	Low	Low	Low
5	Large	High	High	High	High	Low
6	Large	High	High	High	High	High
7	Small	Low	Low	Low	Low	Low
8	Small	Low	Low	Low	Low	Low
9	Small	Low	Low	Low	Low	Low
10	Small	Low	Low	Low	Low	Low
11	Large	Low	High	Low	Low	Low
12	Small	Low	Low	Low	High	Low
13	Large	Low	High	High	Low	Low
14	Large	Low	Low	Low	Low	Low
15	Large	High	Low	Low	High	Low
16	Large	High	Low	Low	High	High

The following table summarizes the characteristics of the sixteen projects and the actual amount of slippage for each.

Project	Months Slip	Description
1	2	8 mos. projected length, significant SW extension to existing product
2	2	6 mos. projected length, SW extension to existing product
3	1	4 mos. projected length, HW and significant SW, new product, technology new to company
4	4	12 mos. projected length, significant HW and SW extension to existing product, HW technology new to world
5	9	18 mos. projected length, significant HW and SW, new product, technology new to company
6	7	9 mos. projected length, significant HW and SW extension to existing product, technology new to world
7	1	7 mos. projected length, HW and SW extension to existing products
8	1	2 mos. projected length, HW and SW extensions to existing products
9	1	7 mos. projected length, HW and significant SW extension to existing product, technology new to company
10	1	3 mos. projected length, SW extension to existing product
11	12	3 mos. projected length, HW and SW, new product and architecture, conducted during organizational change
12	1	4 mos. projected length, SW fixes on an undocumented code base
13	5	6 mos. projected length, HW and SW extensions to existing product
14	3	3 mos. projected length, HW and SW, new product
15	5	21 mos. projected length, significant HW and SW, new platform, technology, multiple options developed concurrently
16	15	14 mos. projected length, significant HW and SW, new platform, conducted during organizational change

Appendix II

The technique applied to data in this paper is the Fisher Exact Probability Test with Tocher's modification[2], summarized here for reference. This approach is well suited for cases where scores from two independent samples fall into one of two mutually independent categories and sample sizes are small. In the case of this paper, the horizontal categories were always schedule slip (on time or late), where the vertical category was one of the five probable causes. After categorizing the data, it is summarized in a table of the following form.

	Low	High	TOTAL
Small	A	B	A + B
Large	C	D	C + D
TOTAL	A + C	B + D	N

Comparing the degree of new content against schedule slip, A is the number of programs exhibiting both "small" slips and having "low" amounts of new content, B is the number of programs with "small" slips and "high" amounts of new content, and so on.

The exact probability of the occurrence of A, B, C and D under the null hypothesis of independence is calculated as:

$$p = \frac{(A + B)!\,(C + D)!\,(A + C)!\,(B + D)!}{N!\,A!\,B!\,C!\,D!}$$

Tocher's modification results in a more statistically conservative approach based upon Fisher's calculation, arising from the possibility that the margin totals may not be found to be fixed given repeated samplings of the same population. Tocher's modification calls for the margin totals to remain fixed, but more extreme outcomes that could occur to be calculated. The exact probability then becomes the sum of the original Fisher calculation and the probabilities of the more extreme cases.

Using the case of degree of new content, the observed data are shown below, with the Fisher Exact Probability calculated as $p = 0.137063$.

	Low	High	TOTAL
On time	6	2	8
Late	3	5	8
TOTAL	9	7	16

A more extreme outcome that could occur with the same fixed margin totals follows, and yields a Fisher Exact Probability of 0.01958.

	Low	High	TOTAL
On time	7	1	8
Late	2	6	8
TOTAL	9	7	16

The final, most extreme outcome that could occur follows, and yields a Fisher Exact Probability of 0.00070.

	Low	High	TOTAL
On time	8	0	8
Late	1	7	8
TOTAL	9	7	16

The probability associated with the occurrence of these values becomes

$$p = 0.137063 + 0.01958 + 0.00070 = 0.15734.$$

Appendix III

The following questionnaire was sent to project managers or team members via email to gain their categorization of four probable causes. The fifth probable cause (Identified Risk) was available from the milestone documentation.

I am doing research on our risk management practices on new developments as a requirement for completing my Master's Degree this summer. If you would take a couple of minutes to answer the questions below, I'd greatly appreciate it. If you aren't the correct person to answer, could you please forward ?

My research looks at five variables, and their correlation to schedule slippage between DP and PSR. Even in the case where a formal DP might not have been observed, answer to the best degree that you can.

Regarding the ________ program:

1. Would you characterize the new content of the program to be **high, or low**?
   If a significant element of the program (technology, tools, distribution channel, organization) would be considered new to your department or new to the world, classify the new content as high. An example of a "high" in new content is where a new technology the company has never utilized before is a part of a project. If it's an evolution of performance, but using similar techniques as used in the past, classify as "low".

2. Would you characterize the degree of disagreement on PSR date between the implementers and management as **high, or low**?
   If the engineers' opinion of when PSR would occur was three months or more different than management expectations, the degree is "high". Otherwise, the degree is "low".

3. Would you characterize the degree of identified risk at DP as **high, or low**?
   Having at least one "show stopper" that you are going forward through DP with would be classified as having "high" degree of unidentified risk.

4. Would you characterize the degree of requirements change past DP to be **high, or low**?
   Having specifications not nailed down, or changing enough to cause confusion or retrenchment within the program would be classified at "high".

Let me know if these questions don't make sense. I appreciate you taking the time to answer.

Regards,
Tim Bennington-Davis