

Managing the Dynamics of Projects and Changes at Fluor

Kenneth Cooper & Gregory Lee

Foreword

Project management is at once one of the most important and most poorly understood areas of management. Delays and cost overruns are the rule rather than the exception in construction, defense, power generation, aerospace, product development, software, and other areas. And no wonder: large projects are classic examples of dynamically complex systems. A large project involves significant accumulations, time delays, feedback processes, and nonlinearities, all features of dynamic systems that research shows are difficult for people to understand and manage. Further, decisions regarding scope, schedule, and budget are frequently made under severe schedule and cost pressure. Learning from past experience is difficult. The long duration of large projects means there are many changes in personnel, organization, management and market conditions between the handshake between client and contractor and the handoff of a finished facility, so it is difficult to attribute outcomes to decisions made months or years before. Project managers commonly believe every project is different, so often discount the applicability of past experience to current circumstance. Managers also tend to blame their people for what are usually process problems. And it is difficult or impossible to conduct controlled experiments that might provide insight into better strategies and policies.

These conditions, while not unique to large projects, are ideally suited for the use of system dynamics modeling to improve policy design and speed learning. The application of system dynamics to project management began in earnest with Ken Cooper's groundbreaking work in the 1970s. In this paper, Ken Cooper and Greg Lee show just how valuable avoiding project difficulties can be. What they have accomplished at Fluor is remarkable. The challenge was not only technical: developing a robust system dynamics model capable of capturing a diverse array of projects built all over the world and carefully calibrating it against data. They also had to develop a user-friendly interface that allows the full complexity of the model to be accessed by managers with no training in system dynamics modeling. Far more challenging is doing so in a way that leads to acceptance within the organization, that encourages the use of the model as an engine of inquiry rather than as a tool for performance assessment and employee evaluation. The history of decision support tools in all fields is replete with examples of valuable models that failed to have any impact as they are rejected by the organizational immune system, or are used by management to monitor and control employees, or are imposed from above without the involvement and participation of users. In this paper, Ken and Greg not only describe the substance of the model and how it can help project managers, but the process through which they have succeeded in embedding the model in the organization. That process was one of organic growth, guided by Ken and Greg, but powered by the project managers and others who used the model, found it valuable, made suggestions for improvement, and spread the word throughout the organization. Importantly, Fluor uses the model exclusively to improve project management. What has been accomplished so far stands out as one of the best applications of system dynamics to important real-world problems. Most exciting, there remains great opportunity to apply the model and learning process, particularly in cooperation with clients and other partners in Fluor's value chain, and throughout the construction industry. As you will read, such applications are already beginning.

*--John Sterman
Jay W. Forrester Professor of Management
Director, System Dynamics Group
Massachusetts Institute of Technology
Sloan School of Management*

Managing the Dynamics of Projects and Changes at Fluor

Kenneth Cooper & Gregory Lee

Executive Summary

We designed, built, tested, and implemented a model-based system to aid project management at Fluor Corporation. The model is set up for and tailored to each engineering & construction project. It is then used to foresee future cost & schedule impacts of project changes, and most important, test ways to avoid the impacts. This “Change Impact Assessment” system has now been used on well over 100 different Fluor projects, a number that is growing rapidly each year. Hundreds of project managers and planners have been trained in the ongoing internal use of the system. In addition to providing a better understanding of the project-wide effects of changes, the cost savings for Fluor and its clients has now grown beyond \$1.3 billion.

Background

“The project was slated to design and build an exciting first-of-a-kind product. But during the development effort, unexpected problems emerged—changes in the design specifications, shortages of qualified people, material supply delays. Costs escalated, and work fell far behind schedule. The project’s future was threatened, and the work was interrupted. Eventually, project objectives were scaled back and the work was completed - years late and at more than double the original budget.

If this tale of development project woes sounds all too familiar, perhaps it is from personal experience, or because others like it are being lamented so frequently in company boardrooms, and reported in business publications with disturbing regularity. It might be a construction firm’s experience in building a power plant, or a software company’s troubles in bringing new systems to market, or the most recently-reported defense program problems, or the automobile industry’s struggle to cut product development costs.

But it isn’t. The product sponsor in this tale was George Washington; Paul Revere supplied the required copper and brass fittings. The special timber that delayed the work’s progress eventually provided the project’s product with its nickname, “Old Ironsides.” The U.S.S. Constitution inaugurated the U.S. Navy and was, in 1794, a new nation’s introduction to the challenge of large development project management.”

--“The Rework Cycle,” Cooper, 1993

Projects and Change Management

Good project performance is important to nearly every successful company. Despite that need, consistently successful project management remains a challenge for most organizations. What makes it such an elusive goal? After all, we understand pretty well how to plan projects. Take a look at the literature (and the training courses, and the many project software packages); you will find thousands of references on project planning and scheduling and estimating. Where, in all that material, is there a cogent discussion of the proactive management of *changes*? Changes from planned conditions are what cause project performance to stray from the objectives set forth in carefully estimated plans -- changes cause most project cost and schedule overruns, project “surprises” and project “train wrecks”. Changes account for a quarter to a half of all costs on most projects, yet the attention paid to proactive change impact management is negligible.

“Well,” you might say, “is change management so difficult? Aren’t there many project change management systems and change procedures?” Yes. And every single one ignores the “secondary impact” of changes. While it is challenging to quantify and

explain, secondary impact is *the single largest source of project performance problems*.

What is secondary impact? It goes by many names...knock-on impact, ripple effects, disruption, cumulative impact, productivity loss. Whatever the label, the impacts are typically misunderstood, unforeseen or under-estimated, and, therefore, mismanaged. To be clear, secondary impact is the effect of changes on the cost of performing the unchanged work. Think about that. Within the industry, procedures are actually quite good for estimating the direct cost of a change -- the specific additional work required to install another pump, or to add a number of feet of cable, and the material cost of the added components. But what if the change requires rip out and rework? What if this is not the first change, but the hundredth? What if executing the work with those changes requires additional overtime in order to finish on schedule? Analyses consistently show sustained overtime to cause loss of productivity (Thomas 1992). Such productivity loss occurs on *unchanged work*— people get tired, and they're less productive on whatever they're doing. Overtime-induced productivity loss means higher cost to perform the unchanged work... hence, "secondary impact." Another example: the project may try to stay on schedule (even with the changes) by bringing on more staff than originally planned. However, in constrained labor markets the new staff often will be less experienced (at least, on that project) than the staff already planned for the work, and they will require more training and supervision. Hence, this also leads to a productivity impact, or secondary impact, of the changes. Through these and several other paths, changes cause productivity impacts that increase the cost of executing the unchanged work. (See "The Project Model" below.) Organizations that do not foresee, understand, and act to mitigate those impacts are destined to incur the surprise overruns that plague so many projects.

Engineering and Construction Industry

Although similar lessons apply to all complex projects, this paper focuses on capital projects in the Engineering and Construction industry --- projects that design and build facilities. These projects require capital investment on which the client seeks to generate a satisfactory return. The better that return, the more successful the project, and the more successful the client. Clients understandably want to achieve for their projects the best cost performance in combination with the best schedule performance.

The Engineering and Construction industry exceeds \$600 billion in annual revenues, about the size of the worldwide automobile industry. Engineering and Construction includes several global contractors, hundreds of multi-nationals, and thousands of local and regional contractors and subcontractors. The markets are as varied as the industrial base, from power plants to pharmaceuticals, infrastructure to chemicals, oil refineries to gold mines. Project sizes range from the very small to tens of billions of dollars. Projects occur in every geography, from the oil sands of Alberta to the mountains of Chile, to remote areas of the Middle East, to the deserts of Australia.

This is the stage on which Fluor Corporation is a global leader. Fluor is one of the world's largest Engineering and Construction firms, with 2008 revenues over \$20 billion and a backlog exceeding \$30 billion. The US-based firm operates in every

major business sector and geography. Its projects are typically market-driven with aggressive cost and schedule targets and evolving client needs. It is the tension among these different objectives that is often the underlying dynamic for generating changes on projects.

In an industry in which overall bottom-line margins are near 3% [Fortune, 2008], there is little room for error. But it is in this setting that *change* is ubiquitous --- changes to performance specifications, changes in project scope, changes in planned plant capacity, changes in operating needs, changes in design features, changes in vendor-supplied equipment, changes in schedule targets....

One author of this paper has worked for over thirty years in the industry, in executive management roles throughout the business. In an initiative by Fluor's Chairman, the author helped quantify the magnitude of business impact associated with project *changes*. A comprehensive quantitative review examined all Fluor projects over several years--encompassing tens of billions of dollars of client investment. For many in the industry, there is a misperception that contractors improve their performance with more changes. This company-wide review was unequivocal in refuting that notion. There is a clear, unambiguous relation between the level of changes and the cost and schedule performance of projects: more changes bring ever-worsening performance on projects. The review showed that improving the management of change impacts could yield large client savings, and it clearly established the business need for, and benefits of, better change impact management. This led directly to the development and deployment of the "Change Impact Assessment" (CIA) system described here.

Project Modeling with System Dynamics

Project modeling has been one mainstay of system dynamics practice for many years. The earliest work in the field has spawned hundreds of assignments, studies, theses, courses, and applications in many industries. In his definitive book on the field, Sterman writes of project modeling applications:" These range from other military and commercial shipbuilding projects to aerospace and weapons systems, power plants, civil works such as the cross-channel tunnel, and software projects...The real leverage lies in using these models so overruns and delays are avoided..." (Sterman 2000). Project modeling is described as one of the most successful areas for the application of system dynamics (Lyneis/Ford 2007).

One author of this paper has worked over thirty years in the development and application of system dynamics project models -- from the original modeling in the late 1970's (Cooper 1980), through refinement of the approach in hundreds of practical applications in aerospace, shipbuilding, electronics, and construction (Cooper 1993).

The authors' paths crossed soon after Fluor had identified and quantified the business need for improving the practice of project change management. The authors and their colleagues first built and piloted and validated a project model to assess change impacts on several initial projects. In the four years since then, we have used that model in the "Change Impact Assessment" system to conduct

thousands of analyses on over 100 client projects. Fluor projects analyzed with this model range in size from less than \$10 million to more than \$10 billion, and span nearly every business sector and geography in the world. We have trained several hundred project managers and planners in the ongoing regular internal use of the model and the lessons from its analyses. In doing so, we have achieved major client cost savings, and changed the way the company thinks about and manages projects and changes.

In the sections that follow, we first describe the project model around which the “Change Impact Assessment “(CIA) system is built. We then outline the range of challenges involved in modeling varied complex projects. While there were many such modeling challenges, we were to learn that there were more practical and organizational challenges in making the system a valuable tool at the company. In reviewing the modeling and practical challenges, we will describe the features of the model, the system, and the process that have been critical to “making it all work”. We conclude with a summary of the large benefits that use of the system has brought to Fluor and its clients.

The Project Model

We are confronted first by the most basic challenge of deciphering the fundamental truths of the dynamics of projects --- no small undertaking, as consistently successful project management eludes most organizations, and has done so for as long as documented history records the performance of projects.

Why do so many projects fail to achieve initial objectives? What are the key contributors to productivity change? What causes rework? Indeed, what role does rework play in projects? (Rework is a phenomenon that is *ignored* by the vast majority of project literature and project management tools, yet is a major determinant of performance.) Why do progress estimates often miss the mark? How does engineering performance affect construction performance? How do the many factors influencing projects interact with one another over time?

On these most basic project modeling issues, we were aided by a substantial body of work in project modeling with system dynamics. The framework of the project model used in this work is described here, a product of many years of work by the authors and their colleagues, past and present.

The model used as the engine of the Change Impact Assessment system simulates the dynamics of project performance from engineering start through construction completion. For each point in simulated time, the model computes staffing needs, work progress, productivity and its key determinants, such as overtime usage, vendor support, experience levels, and rework. From a base condition, model users can simulate a wide range of “what if” test cases in order to quantify and diagnose in advance the impacts of changing conditions, and how best to mitigate adverse impacts.

The Rework Cycle

Consider that in the capital projects arena, virtually every major project requires a significant amount of custom engineering—no two projects are quite the same. Now, the conventional view of a project is a collection of many discrete tasks, each task with a clear start and end. If only it were that simple...start each task as planned, and finish it as scheduled with the budgeted resources. But on many projects, things happen that drive work items to be done out of sequence...to be just partly finished when first issued...to be worked at productivities other than as planned...and to be reworked.

Therefore, on engineering-intensive projects, it's helpful instead to think of not just individual tasks, but a *flow* of work (Figure 1). That flow of work depletes a pool of work "to be done"; the work flow is executed by people working at some level of productivity. Now, suppose that the executed work products (drawings / documents / software code, ...) are not simply done once-through—never to be touched again—but are instead subject to *rework*...some degree of revision and refinement. And the engineering rework needed may not be recognized until weeks or months later, when it is discovered by checking, testing, or the attempt to build to that design. *Until* then, the rework remains undiscovered. Until the rework need is detected, project management understandably views that part of the work as finished. Meanwhile, other design work proceeds, and if it is dependent on the to-be-revised information, it could end up needing reworking as well. And so the rework cycle continues; in complex engineering projects, many rounds of revisions are needed to reach completion.

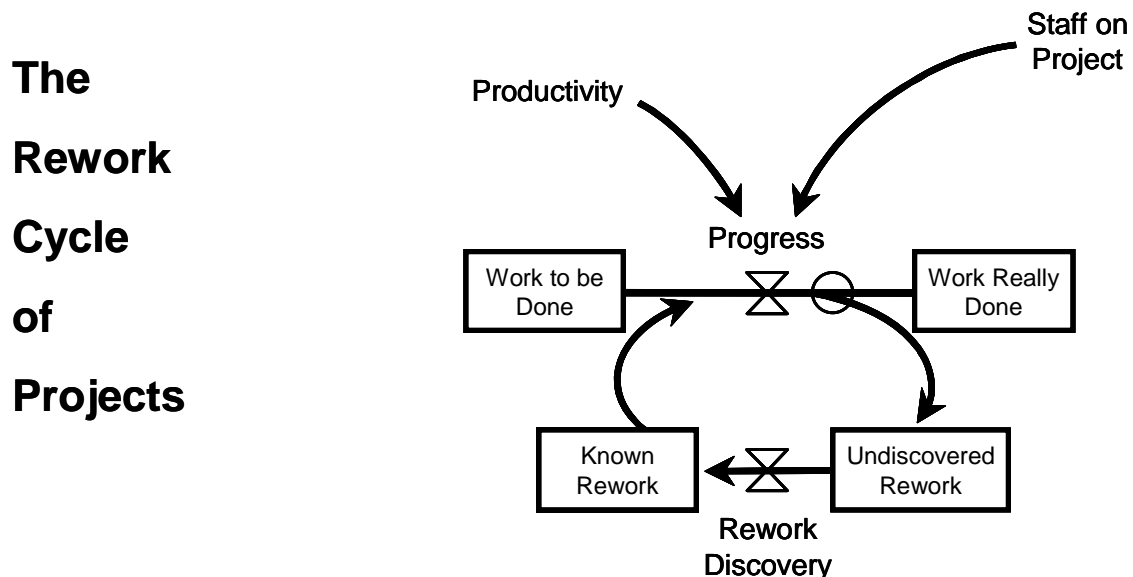


Figure 1: Viewing project work as a flow, executed by people working at a variable productivity, and performing work that may need subsequent rework...the need for which may go undetected for some time.

Recognizing these facts about the way projects really work improves our ability to think about (and analyze) how change impacts occur, and what can be done to improve project performance. Consider what happens when engineering/design changes occur along the way—changes of any sort, such as design scope additions, or delays in needed information. To the extent that such changes affect the productivity on, or rework of, *unchanged* work, there is a “secondary” impact of the changes, an impact that is above and beyond the direct cost of the changes themselves. So, how might changes affect the productivity on the *unchanged* work?

Changes and their effects on project dynamics

In Figure 2, project changes (added or changed design work) are represented by the “plus” and “delta” signs. The changes have immediate consequences that are clearly visible--the direct effects (shown in blue arrows below) are to grow the estimated hours at completion, and, without schedule relief, the staffing needs of the project.

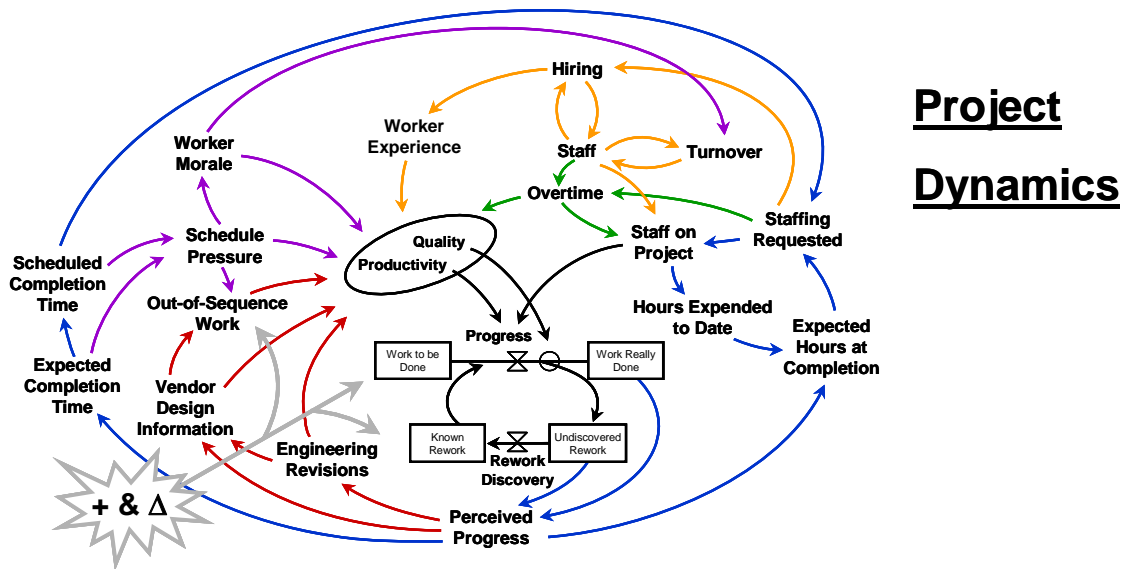


Figure 2: A diagramed version of a story told by thousands of project managers, a story of impacts on productivity, rework, and the interacting conditions that drive those impacts.

Increased staffing needs could lead to higher overtime usage (green arrows). More sustained overtime, with the resultant fatigue, reduces productivity. This is one of the most widely studied productivity-affecting conditions, and the first among those examined here. Note that such overtime fatigue affects the productivity of individuals on *all* the work they perform—hence, a “secondary impact” of changes.

If more people are needed to accomplish the increased work, additional hiring likely means bringing on people less experienced than those already on the project,

especially in labor-constrained markets (orange arrows). This, too, reduces productivity (and increases rework). Secondary impact.

Changes, slowed progress, and revisions can disrupt the exchange of information with vendors, and needed vendor data may be delayed (especially in markets in which vendors are working near capacity, their response time to changes can be slowed). Slowed vendor data contributes to out-of-sequence work and further reduces productivity (red arrows). Secondary impact.

Finally, as schedule and budget pressures mount and more rework occurs, there can be a systemic effect on the morale of the staff, causing a further impact on productivity (purple arrows). Especially in tight labor markets, this effect can also mean that engineers choose to leave the project (or the company). Higher turnover means...more overtime, or more new hires. Secondary impact.

These phenomena are reflected in the simulation results shown here in Figure 3a-c. The plots summarize the conditions from six scenarios, a plan or base case (dark blue) and five different change impact scenarios. Each impact scenario has a successively higher level of change (added in equal increments). These cause engineering labor costs to increase disproportionately (3a), as base productivity (on the unchanged work) is impacted more and more (3b) by such factors as vendor data delays, out-of-sequence work, and increased revisions. Meanwhile, construction begins and is working to a set of engineering documents that is, to their view, delayed and changing (3c). Craft work is often performed under intense schedule pressure, so changes can cause further productivity impacts from skilled labor constraints, delayed vendor-supplied equipment, craft crowding in confined spaces, extended overtime, and increased rework in the field.

Figure 3: Each scenario shown here has a successively higher level of change being tested (added in equal increments)—causing higher staffing with lower productivity, slower progress, and higher craft labor costs.

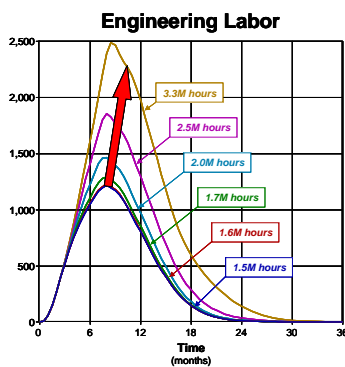


Figure 3a: Successively higher levels of change cause labor costs to increase disproportionately, as a result of secondary impacts.

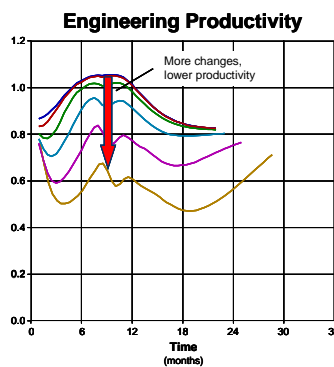


Figure 3b: With more changes, productivity will be impacted more... this productivity loss will be exacerbated by increased revisions, vendor data delays, and out-of-sequence work.

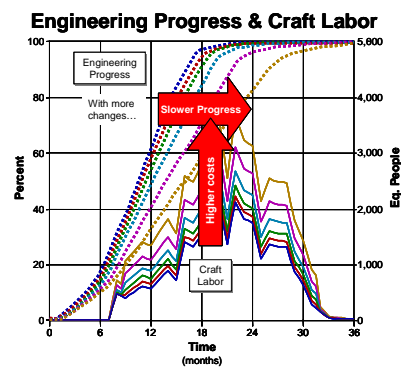


Figure 3c: Despite higher engineering effort, the combined effects of changes and lowered productivity will cause slower progress – and less mature engineering will cause field productivity loss and higher craft labor cost.

In summary, changes cause a set of productivity impacts on the base work in engineering and construction – this is the essence of “secondary impact” – translating to higher costs and later completion of the project as a whole. (There is little debate about *whether* such effects occur; it is just a question of how *strong* each of the effects is--and the strengths of the effects depend on the specific conditions on the project, the schedule, and the markets in which the project is operating.) While the amounts of impact vary with different changes on different projects, we have observed that the *secondary* impact can easily be as large as the *direct* costs of the changes, and sometimes 2, 3, or 4 *times* the direct change costs.

With this view of secondary impacts, it is easier to see how a project with many changes operating on a rapid schedule in tight labor and vendor markets, and with challenging productivity conditions could experience a significant cost increase. Indeed, analyses of hundreds of projects show that the “secondary impacts” of changes – because they are traditionally difficult to foresee – often represent the major source of project cost surprises. By whatever label is attached to them (ripple effects, productivity loss, knock-on impact...), the secondary impacts of changes are generally large, underestimated, unanticipated, and, thus, unmitigated. They have historically constituted the single greatest challenge to good change management, and to strong project performance.

The rework cycle and the interacting set of productivity factors above are crucial to understanding how changes affect project performance. Even more important, this view provides insight into where management intervention can do the most good in reducing, even preventing, secondary impacts.

Modeling challenges

In focusing the project modeling on proactive change impact management, we were confronted with several specific challenges and needs that are listed below. The modeling had to have the ability to...

...foresee future impacts. Retrospective analysis is useless when the objective is, as it has always been at Fluor, the proactive identification and avoidance of cost impacts. Indeed, the use of a “change impact assessment” method could have focused simply on advance pricing of the changes, but instead, Fluor has focused on *avoidance* of the changes’ impacts. To serve that goal, the impacts must be foreseen in order to develop effective mitigation; what we say in all of our talks (with trainees, project managers, and clients) is, “You cannot mitigate what you do not foresee”. With that emphasis, the use of the tool has moved earlier and earlier in the project life cycle, and is now most often used at the start of project engineering.

Along with this requirement, there has been the need to demonstrate that the future performance of the project as foreseen by the model is in fact accurate. Having completed many applications at Fluor, we can now assess the accuracy of the forecasted performance, and time after time, the results have proven to be extremely accurate. As one project team noted, “the tool simulated our staffing almost perfectly.” Another team described how, contrary to expectations, the model foretold a different pace of engineering progress yet to come, an outcome that occurred just as simulated. Yet another project team told of the “uncanny accuracy”

from the simulation as the project progressed. This experience has been repeated consistently in the many uses at Fluor, and has contributed greatly to the credibility of the model.

...quantify impacts of engineering changes. As obvious as this need sounds, most industry and academic efforts to examine change impacts have focused exclusively on construction changes and impacts. We believe this has been due to the mistaken belief that, because most of the project cost is typically in construction, the only important changes to address are construction changes. (This oversight may have been coupled with or reinforced by the lack of a methodology to examine the cause-effect linkages between engineering and construction performance.)

Contrary to that historical emphasis, our analyses consistently demonstrate the highly-leveraged project-wide impacts of changes rooted in engineering. In Figure 4, the cost impact of a range of engineering changes is charted for engineering (on the left) and construction (on the right). The X-axis describes the successively higher levels of direct engineering change being tested (5% to 25% of base scope). The same magnitudes of changes are also tested in different time frames, with changes that extend deeper into engineering shown to produce higher degrees of impact. (While these numerical results are not unusual, the exact levels of impact will vary depending on the changes themselves and the project conditions.) Also note that more changes create not just more impact, but *disproportionately* more (note this reflects the productivity impacts seen above in Figure 3b). This phenomenon is known to some as “cumulative impact”—the analyses demonstrate the fact that changes that occur in the presence of other changes cost more than if they occurred in isolation. Hence, the last and latest changes tend to be the most expensive (and, thus, when looking for cost savings, these changes are the most highly-leveraged candidates to be eliminated).

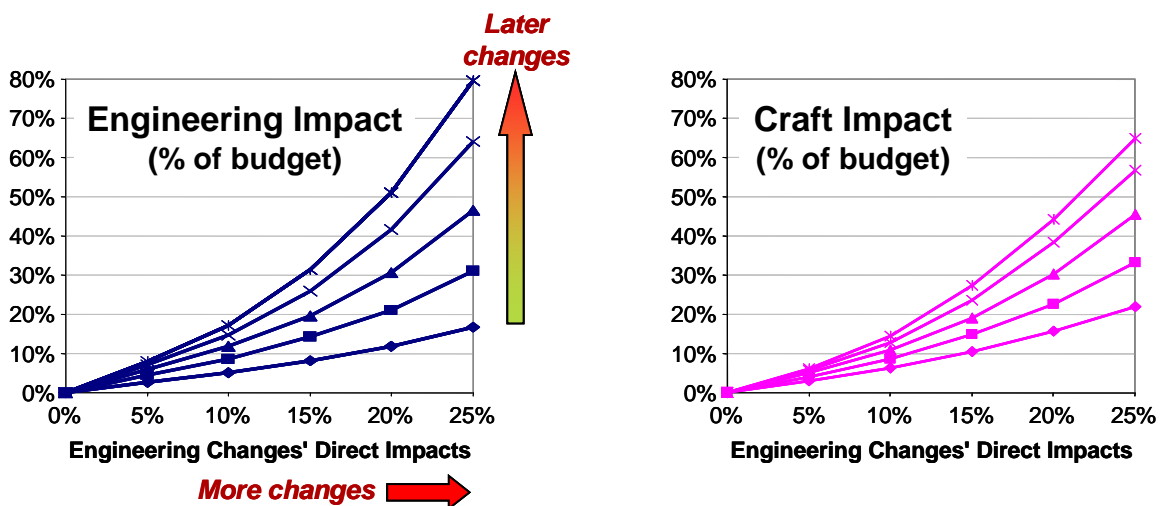


Figure 4: Secondary impacts of engineering changes permeate the entire project. The amount of impact varies with the amount of changes and with the timing of the changes. More and later changes create not just more impact, but disproportionately more impact (reflecting the productivity impacts shown in Figure 3b).

...**quantify impacts of information delays.** When changes are discussed in most settings, the examples tend to focus on scope changes, i.e. changes that add some measurable effort or direct cost. Such changes do have secondary impact, as we've noted here. But what is too often overlooked are changes with low or no added direct effort. These impact sources include, for example, late or changing preliminary engineering (performance specification details), or late "FEED" (Front End Engineering Development)--which is preferably at or near completion before detailed engineering and construction start. These information delays are "changes" that may add little or no direct scope effort. However, they can significantly affect productivity on any work that is technically dependent upon the delayed information. Our analyses have found these "low-direct-cost" delays to have significant impact on engineering and construction performance (see Figure 5). Reported in the chart are results from many different project analyses of FEED (preliminary engineering) that is delayed beyond the start of the detailed engineering work. The X-axis describes how far into detailed engineering the last of the FEED information gets resolved. The impact charted is the percentage cost increase in detailed engineering. Each band of color displays the range of cost impacts quantified for a given amount of FEED missing at the start of the detailed engineering work. The overall pattern is clear and unsurprising...the more deficient the FEED at the start, and the longer it takes to resolve all FEED issues, the greater the cost impact. Foreseeing the amount of impact is a significant aid to projects that are planning when it makes most economic sense to transition from FEED into detailed engineering—this is, for example, exactly the analysis recently performed for a Fluor client on a major chemicals plant project, on which it has been decided to postpone the start of detailed engineering, thus allowing the FEED effort to mature further and to achieve lower project costs.

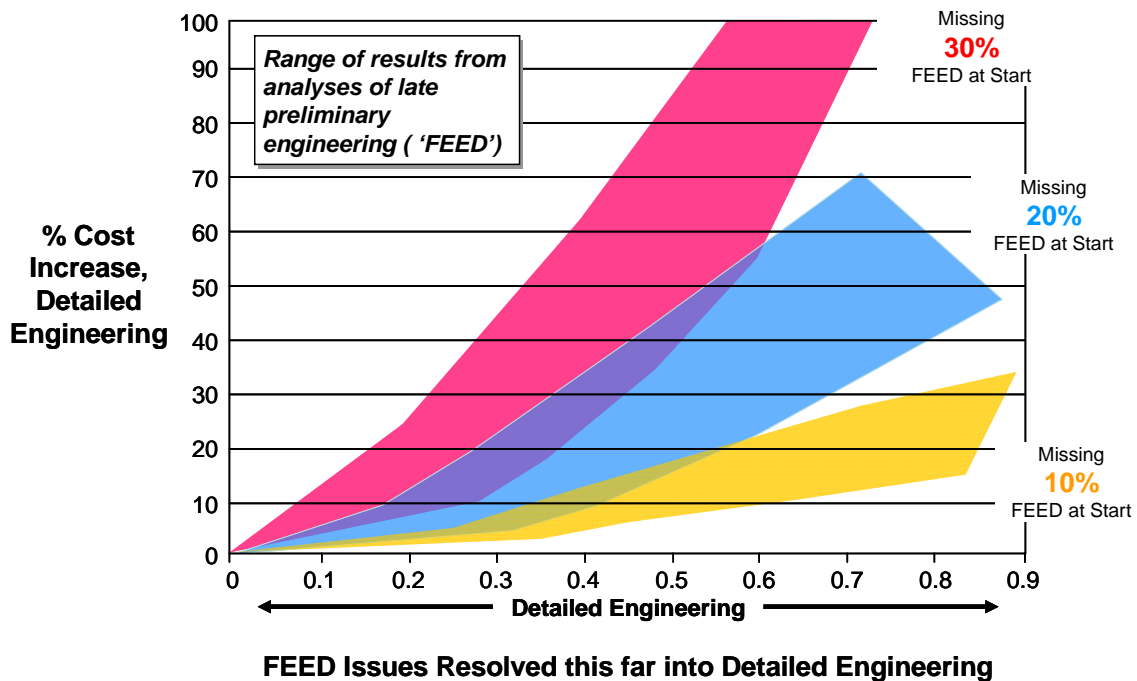


Figure 5: Even with no added scope, late information can cause productivity loss and cost increase in Engineering. In addition, there are construction cost impacts that depend on the degree of engineering-construction overlap.

...identify the timing of future impacts. Foreseeing amounts of impact is helpful, but understanding the future timing of the impacts helps determine *when* preemptive action needs to be taken. Moreover, understanding the timing is important to understanding *how* the “secondary impacts” occur, and thus, determining *which* preemptive actions should be taken. Coincident timing can easily be confused as causality. Thus, there is a particular challenge in understanding secondary impacts, because they can occur far later in time than the precipitating change events--changes that happen early in an engineering stage can have impacts many months or even years later. Waiting until the impacts start to manifest themselves can be too late to initiate effective preemptive action (see Figure 6).

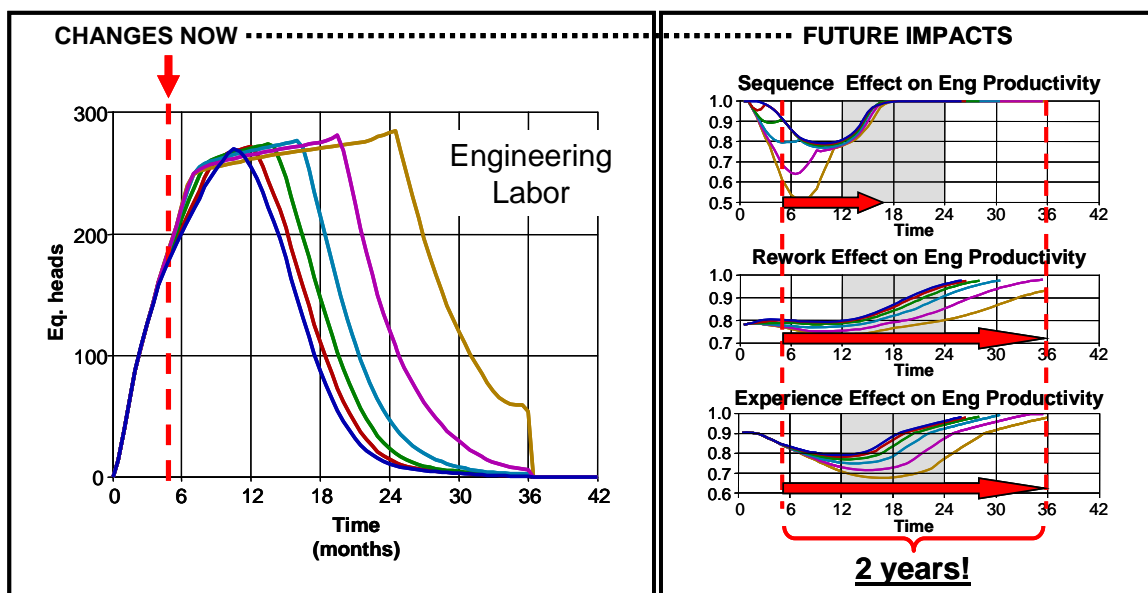


Figure 6: Advance quantification and diagnosis – how much, when, why

...diagnose the causal components of the impacts. Knowing in advance the amount and timing of change impacts could be all that is needed if the primary purpose of the capability were to be just pre-pricing the impacts. But because the objective of the Fluor system is not just to quantify the impacts, but to reduce or avoid them, it is critical that the tool illuminate *why* the impacts occur. Seeing the cause-effect paths through which the productivity impacts are transmitted helps identify what advance actions would be most effective in reducing the impacts. For example, if sustained overtime is forecast to be a major source of productivity loss, curtailing the amount or duration of the overtime will reduce the cost impact. If out-of-sequence work is a big contributor, expedited resolution of outstanding design issues will have high leverage. If engineering revision activity is foreseen to cause field (construction) productivity loss, it would reduce costs to postpone the start of construction. (“Going to the field too early” is a widespread temptation and costly practice in some parts of the industry; the most experienced and battle-hardened managers know this, but we have seen that having advance analyses to support the decision to postpone field

work is often the difference between “sticking to the plan”--despite changed conditions and expensive results--and achieving major cost savings...see the next challenge.)

...examine scheduling options and their effect on cost impacts. This modeling challenge reflects an important management need. Clients of the Engineering and Construction industry understandably want the best performance on every dimension of their projects. At some point, however, there are tradeoffs, and clients have priorities that would lead to different decisions being made if the tradeoff between cost and schedule were clear, explicit and quantified. In our “change impact” analyses at Fluor, we now routinely provide analysis results showing (and explaining) how much the project would cost under each of the several schedule options (see example in Figure 7). Project teams as well as clients find value in this part of the analyses. As a result, many projects have been proactively rescheduled, and have been more successful; the cost savings from this area alone have been hundreds of millions of dollars.

Different construction schedules can improve productivity, reducing change impacts and saving costs for clients

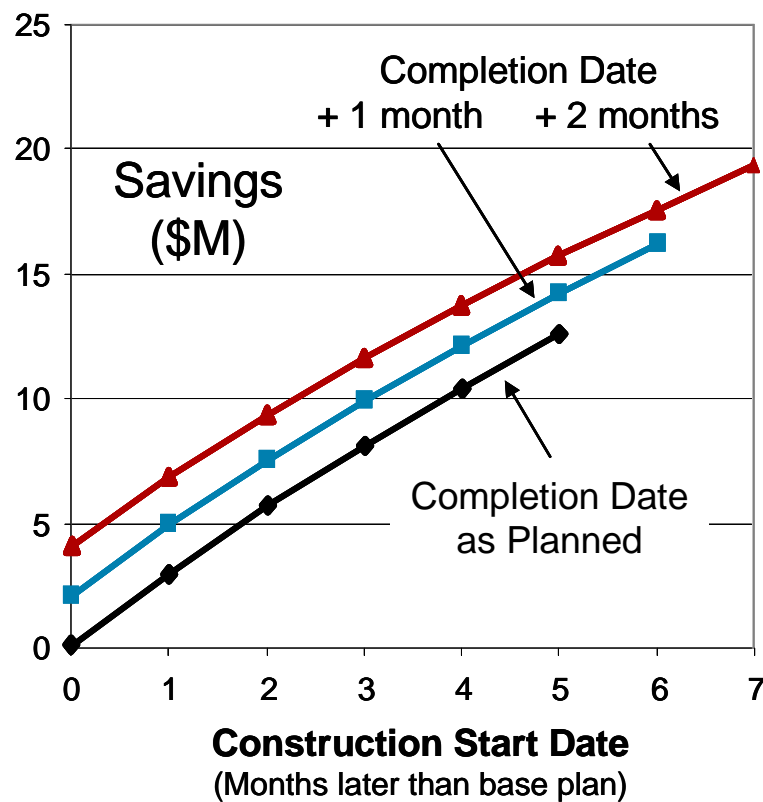


Figure 7: A chart of analysis results (from a recent trainee), showing tradeoffs between (a) costs and (b) construction start and completion dates.

Practical Operating Challenges

Beyond the modeling challenges described, the overarching practical challenge has been the delivery of the capabilities to a diverse range of projects in a timely, low-cost, clear and credible form. The system and the process needed to be able to...

...be usable by project managers and planners throughout the company. The model needed to be understood and accepted by project management teams throughout Fluor. This was needed in part so that the teams could use the model correctly. But it is even more important that they understand how and why the forecasted project performance impacts occur so that they can design effective mitigations, and communicate both the impacts and the mitigations clearly with their clients.

To address these needs, a comprehensive training program has been developed and implemented throughout Fluor. The training has three primary audiences, each with its own objectives. *First*, there is an introductory course intended for every project manager and planner in the company. The material explains the importance of managing secondary impacts and the typical causes of those impacts, and then introduces (usually via live demonstration) the model's capability to foresee and help mitigate the project performance impacts of changes. The same material is provided to every audience, whether they are clients, Fluor executives, sales managers, project managers, or planners.

Second, there is a course designed just for those who will be direct users of the model. They are given more description of the content of the model, and a series of practical exercises in using the model software. In this multi-day course, each person conducts project analyses, and must prepare and deliver management presentations of the analytical results. There is a practical and written exam that each must pass in order to become a certified user of the model. Only certified users are granted access to the model through Fluor's intranet.

Third, there is a course targeted exclusively at project managers. Project managers are the primary "clients" of the findings from these analyses. It is the project manager that must lead most project actions that are aimed at impact mitigation. The objective of this one-day course is to ensure that Fluor project managers know what to expect from the project model users' analyses, and know how to discuss the findings with their project colleagues and clients. This training has become a standard required element in the Fluor project manager training curriculum.

...reflect industry and company standards, while being customized to each project's own conditions. Analyses of productivity impacts often confront one of two criticisms: (1) 'you didn't use industry factors'; or (2) 'you only used industry factors'. In order to reach the right balance of "accepted factors" and project customization, we adopted a three-part solution in establishing the strengths, or sensitivities, of the productivity conditions for each project's model (see Figure 8).

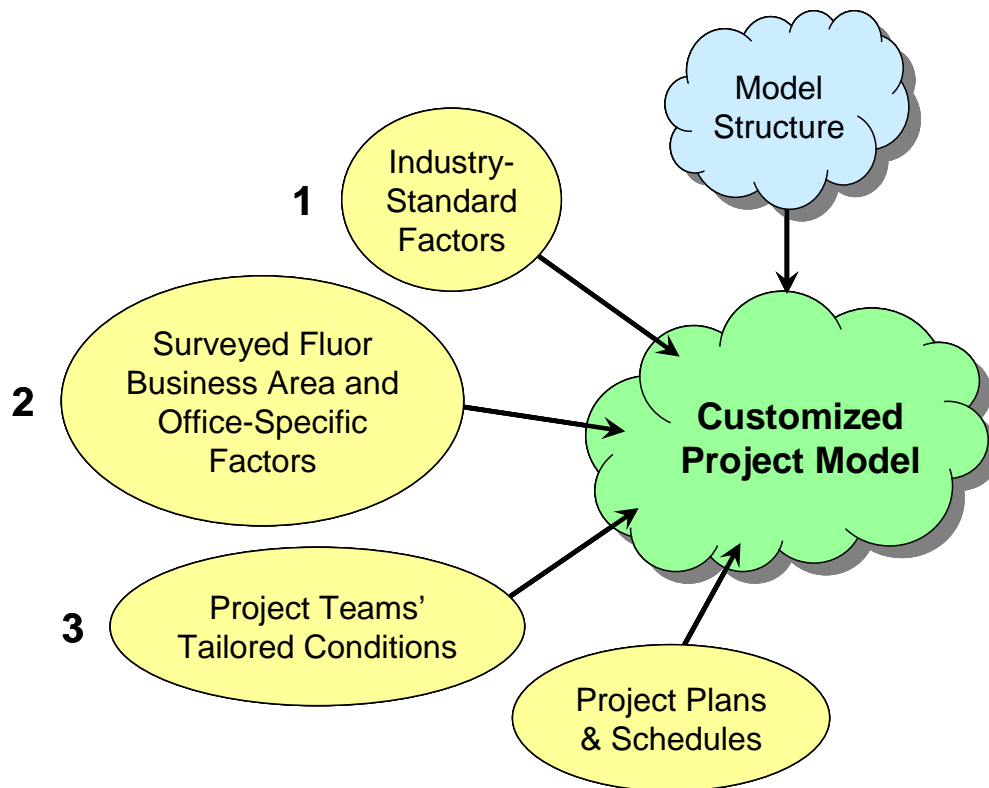


Figure 8: Industry benchmarks (1), company data (2), and project market conditions (3) are combined with project data in the model structure, to provide a customized model of each project.

First, we provide numerical benchmarks from a set of references to several “industry” studies and surveys of productivity impacts. Ranging across topics from overtime use, to worker experience levels, to physical overcrowding, the references include publications from organizations such as The Business Roundtable, Construction Industry Institute, National Electrical Contractors Association, Army Corps of Engineers, and more. In setting up a project model, the project team may choose to base their assessment on those industry factors.

Second, the team may invoke the numerical benchmarks established for different Fluor business areas and offices. To ensure the project models reflect current market conditions, we periodically conduct a company-wide survey of all senior managers and planners; the purpose of the survey is to identify the strengths of key productivity effects in every business area and office. The numerical results of the survey form a large database of productivity factors; to date, these surveys have obtained results from managers whose Engineering and Construction industry experience totals over 30,000 *person-years*. The surveyed productivity factors are a second set of benchmarks the project can use in setting up their model.

Third, each project management team participates in a set of interviews in which the project-specific conditions are discussed (such as the regional labor market, the specific vendor data needs, and much more). In those interviews the project team further customizes the productivity factor settings for their model (see “The Process” below).

As a result of using these three sources, the model and analyses are, while based on standards, customized in a disciplined manner to the peculiarities of each project, and the markets in which it is being conducted. This use of standard factors that are customized to each project provides for the numerical forecast accuracy noted in the first modeling challenge (see “...foresee future impacts” above).

...be deployed rapidly and inexpensively to each project. Project models can be developed to achieve all of the objectives cited in the list of modeling challenges. However, a significant practical challenge here was that we were to achieve all this for less than 1/10 the cost and time typical of developing custom-tailored project models. In order to meet the objective of proactive impact mitigation, each project model needed to be set up quickly enough that analyses could support early diagnosis and action. The cost needed to be low enough to be little or no obstacle to implementation. We achieved this degree of cost and time reduction through a combination of a standardized implementation process and a software system wrapped around the model, as summarized in Figure 9. We describe each aspect below.

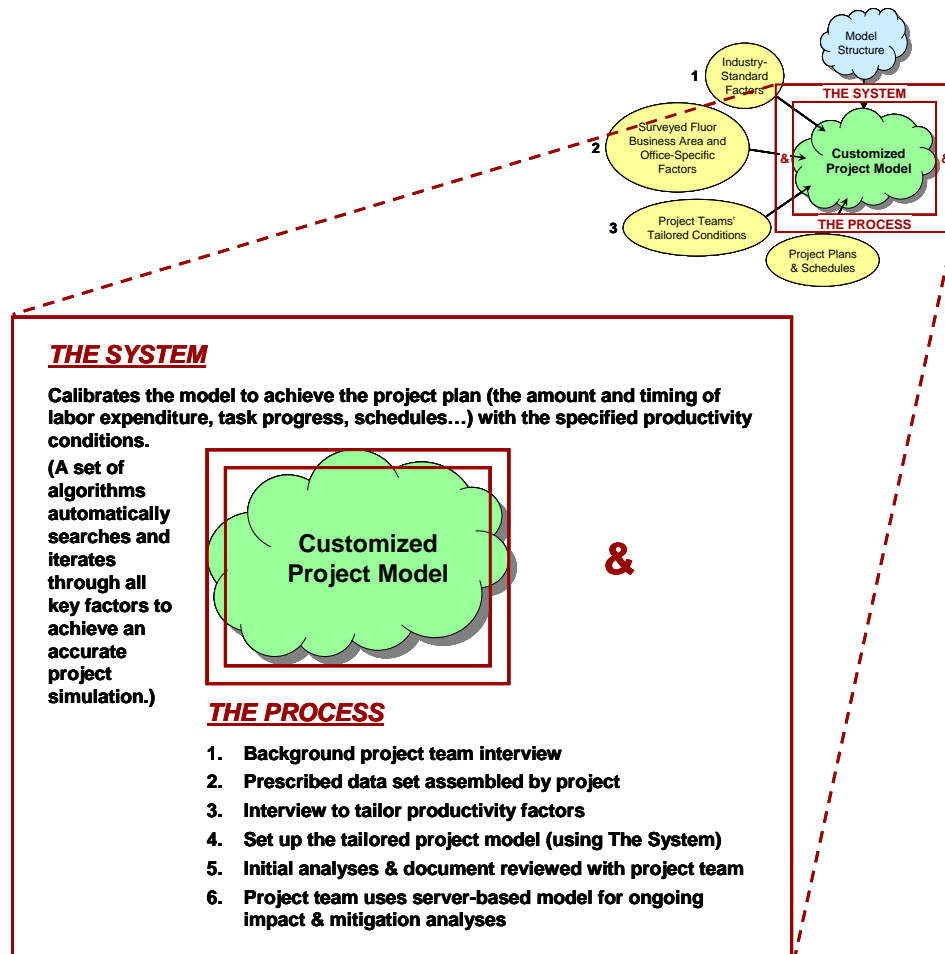


Figure 9: A standardized implementation process and a software system enable rapid, low-cost deployment to each project.

The Process

A standardized implementation process has enabled the rapid setup, delivery, and continuing use of well over 100 project models at Fluor. All projects that meet specified criteria are required by company policy to employ the Change Impact Assessment model. When such a project begins, the project manager and other project team leaders, as well as the individual designated to be the project's user of the model, join in an initial telephone interview with the modeling team. The objective of this first call is to discuss the project along several prescribed dimensions.

After the first call, a standard data input sheet is completed by the project team; the data describes the project's plans and schedules, along with any changes known or anticipated to date. The data input sheet has been designed to require low effort, drawing on information that is readily accessible to the project, in a spreadsheet format that is easy to use.

A second telephone interview follows, with the same participants. In this second call, the project team discusses and specifies the productivity factor sensitivities that will be used in the project model. Drawing upon industry and company benchmark factors (as discussed above), the team discusses differences in the project's characteristics and regional markets to adjust the factors to their own conditions.

With the results of the first two calls and the data on project plans, the modeling team sets up the tailored project model. Using the system developed for this purpose, the model can be set up and customized in a matter of days. Then using the customized project model, the modeling team conducts a wide range of initial analyses and prepares a briefing document for the project team. The purpose here is two-fold: (1) conduct analyses that are of particular interest and value to the project, as identified in the telephone interviews; and (2) illustrate the range of analyses that subsequently can be conducted by the project team with their model. As in all briefings and training, this document emphasizes the importance of the advance mitigation of identified impacts. The document is unique to each project, but employs a modularized set of components that are reusable in these briefings. Areas of analysis differ among projects, depending on interest and need, but some areas that often are examined include: prospective engineering and construction changes (systematically varying the magnitude and the timing of the prospective changes); vendor data availability; speed of design review decision-making; timeliness of agreeing on the resolution of changes; availability of preliminary (FEED) engineering; timing of engineering milestones, and construction start and completion targets. The modeling team often conducts and displays analyses that combine several of these conditions, in order to illustrate the degree of impact leverage and cost savings achievable (see Figure 10).

Combination Mitigations

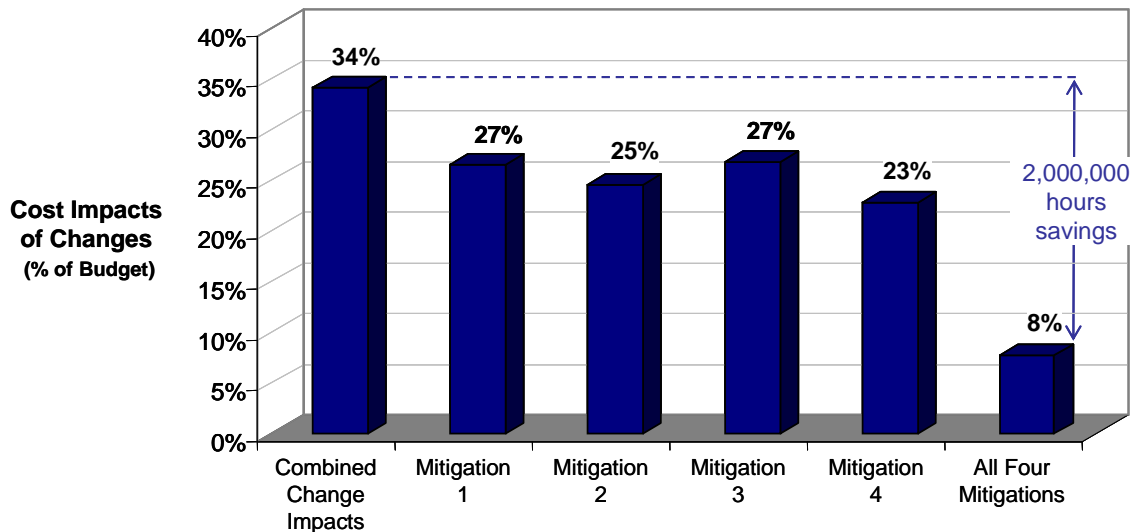


Figure 10: Analyses for projects identify cost savings—over 2 million hours of savings in this one example of combined mitigation actions.

Once the briefing document (typically 20-25 slides) is assembled, it is the subject of a two-hour telephone briefing with the project team. From this point forward, the project's model is loaded onto the Change Impact Assessment system on Fluor's server; there the model can be accessed via the system by the project's designated and trained user, to update and conduct ongoing analyses for the project.

The System

The system around the model was developed with two key purposes in mind, rapid model setup and relatively easy use.

Model Setup

After the first two calls with the project team, and receipt of the project data, the model is set up using a system that automates much of the customization process. Hill-climbing algorithms enable rapid calibration of the model to the project plan and conditions. The system calibrates the factors in the model by conducting an automated multi-dimensional set of parametric adjustments over dozens of iterations. The system searches across productivity factor strengths and timing constants, in order to allow the model to re-create accurately the as-planned project. Characteristics for which the search seeks to optimize accuracy (see Figure 11) include the planned cumulative spend of engineering and construction hours, staffing profiles and timing, work progress plans, as well as the strength of each productivity factor (as specified by the project team in Call 2). Once the as-planned project conditions are simulated in a base case for the project, a wide range of initial "what if" impact and mitigation analyses (as discussed above) is conducted in support of briefing the project team.

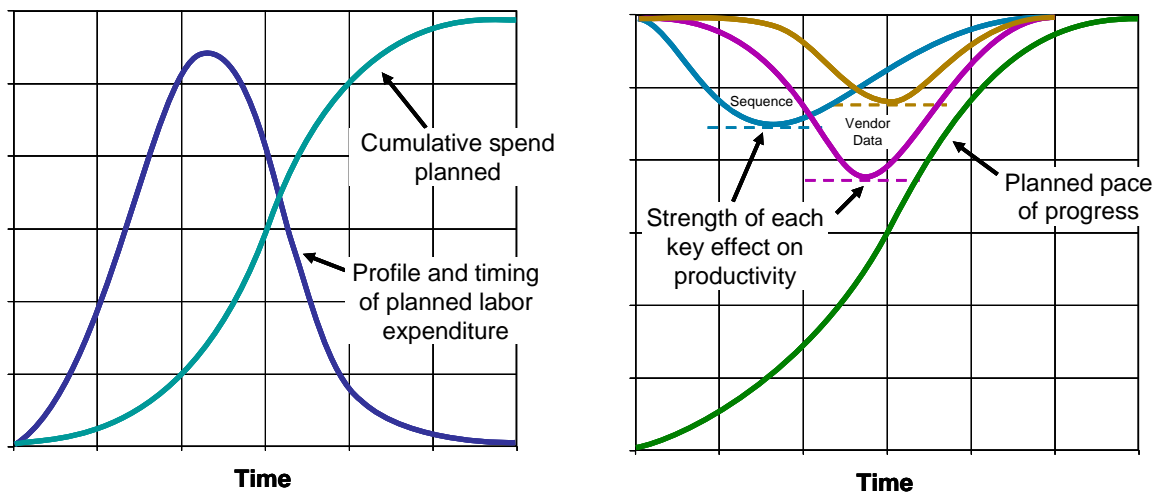


Figure 11: The system calibrates the model differently for each individual project, to replicate its planned performance in terms of the magnitude and timing of costs, scheduled work progress, and productivity and market conditions.

Model Use

After the modeling team completes the setup and the initial analyses, the customized model is set up for the project's ongoing use on Fluor's server. The system interface surrounding the model was designed to make the model easy to use, while retaining the diagnostic value of the available output results. To accomplish those ends, the format for specifying "what if" test conditions was standardized to enable easy execution (see Figure 12 as example). Further, the system organizes the model output into a series of reports, charts, and a wide range of user-selectable plots of the project's dynamics (see Figure 13 as example). The intent is to provide diagnostic explanation of the results in a format and language that is clear for both the user and the management audience. As always, the emphasis in the displays is providing management with the information necessary to understand the amount, sources, and timing of future project performance so they can identify effective preemptive mitigating action (Figure 14).

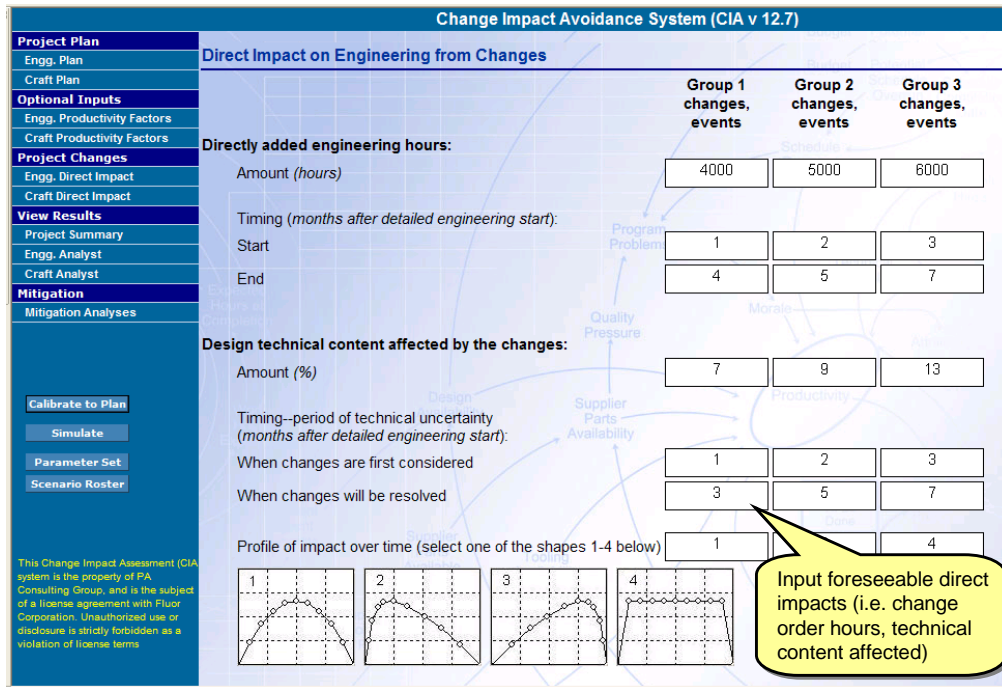


Figure 12: The project model user specifies changes to be tested via the system interface.

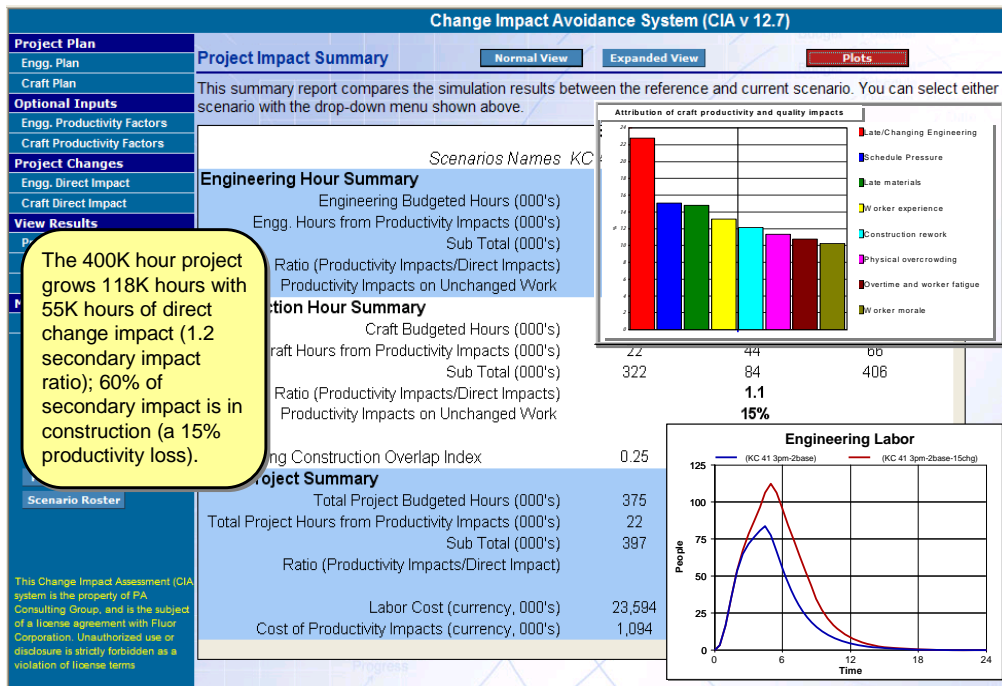


Figure 13: The system provides summary reports and cause-effect diagnostics.

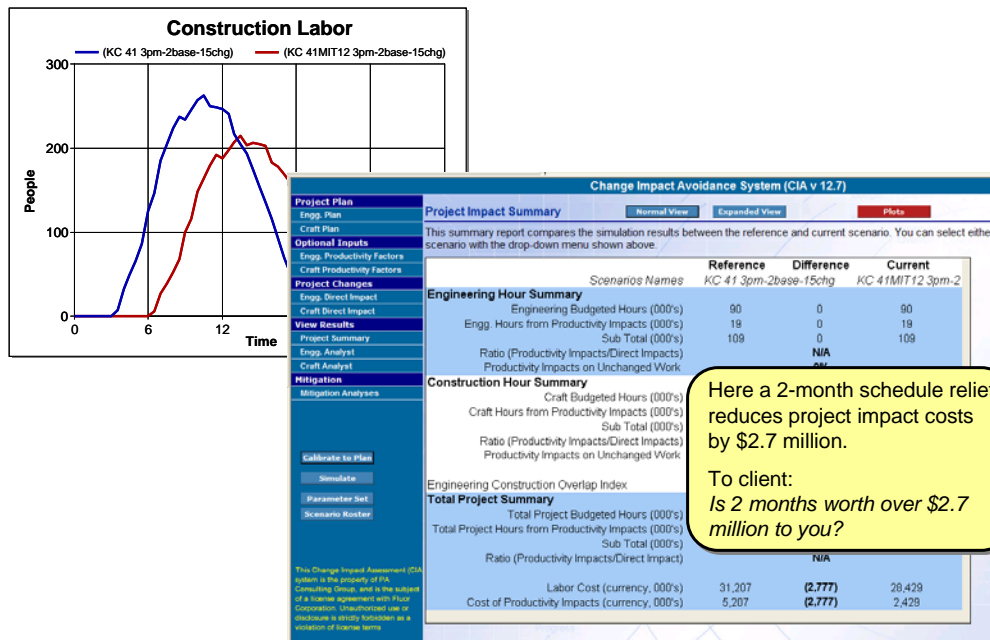


Figure 14: The final step of every change impact analysis is evaluating mitigation options and tradeoffs for review with management and the client.

Impact and benefits of the Change Impact Assessment (CIA) system

From the beginning of this effort, it was clear we needed to alter long-held perceptions regarding the magnitude and extent of project change impacts. It was important that the key points described in this paper reach many audiences... executive management, project managers, department managers, planners and schedulers, even clients. The first overall message was that improved change impact management would significantly improve project and business performance. But adding to this message was that it is *not* a “zero-sum game” -- Fluor and its clients would *both* benefit from improving change performance. It was this latter element that proved to be the key in getting people first to listen, and eventually to become strong advocates. Succeeding in communicating those messages, and now the growing use of the system at Fluor, have generated both qualitative and quantitative benefits.

A language for understanding and communicating the effects of change

Every senior cost and scheduling professional has experienced the daunting task of communicating forecasted overruns late in a project. What has been needed is an entirely different way to understand and discuss change events and their consequences. The “project model” described above has been the key to overcoming this challenge. It provides an experience-based understanding of the dynamics flowing from change events, a common language and (most importantly) a “picture” of how it all fits together. The impact of providing such a construct cannot be overstated. Where prior practice in the industry was to add estimated change “impact factors” to avoid understating what experience suggested would be the ultimate cost, CIA analysis builds an understanding of the causal mechanisms of impact, thereby enabling proactive intervention. Cost-and-schedule professionals’ reaction has been

one of relief. They knew the impacts were real, but had not had a language to discuss them or a mechanism to analyze them, let alone foresee and proactively mitigate the impacts. Use of this system at Fluor has taken change impact dynamics that have been difficult even to describe, and has put them into a language and a set of effects that are understood.

A proactive and mitigation-focused mindset

Change management has traditionally been a reactive, and sometimes retrospective, process that focused simply on documenting near-term or even past direct costs of changes. CIA has altered that focus in Fluor to be a proactive view—looking ahead to future impacts—so as to be able to advise clients more effectively and accurately about the true costs of changes in advance. Taking it even a step further, as we have emphasized throughout this paper, this new approach emphasizes mitigation as an integral part of the change impact assessment process. We emphasize in all of our training that no analysis is complete without consideration of ways to avoid the cost impacts of change.

CIA has empowered project control teams to illuminate impacts yet to occur and propose alternatives while there is time to affect outcomes. Project managers now have a way to approach their clients with impact mitigation alternatives and explanations of tradeoffs, such as the cost-schedule tradeoffs shown in Figure 7. Senior management can now intervene with their client counterparts when project level actions cannot be taken.

A generation of managers trained in this proactive cost-reducing approach

Major training initiatives are carefully monitored at Fluor. It is reasonable to use the level of resources allocated to a particular area of training as one indicator of organizational priority and expected return on investment. Using this yardstick, the CIA initiative enjoys both high visibility and priority. In the last three years, Fluor has trained more of its staff in change management than in any other area of its business. The resources dedicated to this effort represent significant and tangible evidence of the value CIA has brought to Fluor and its clients.

As a result of this ongoing training—in every Fluor execution center in the corporation from Southern California to New Delhi—we are teaching an entire generation of managers and planners this proactive cost-reducing approach to project change management. As we describe above, different courses are used to reach several audiences; the numbers are indicative of the priority attached to this work...

...Over 3,000 project managers, engineering staff and project controls personnel have attended the initial level of training. Business line management has made this level of training mandatory, with near total compliance.

...We have trained over 250 certified users of the system, each graduate successfully completing several days of intensive skill development (including both written and practical examinations).

...More than 300 project managers have attended a program developed to meet their special need to understand how to use the analyses, particularly with clients.

Real dispute avoidance

The worst outcome for a project that does not perform to client and contractor expectations is a formal contractual dispute between the parties. Such a dispute is one of the most costly and diverting activities that a company can undertake, and yet such disputes often occur in the industry, when projects experience change and overruns. With disputes there is likely to be relationship and reputation damage, and the attendant loss of future business. There can be large out-of-pocket costs to all parties—a single large dispute can consume tens of millions of dollars in legal fees. In addition, significant time of professional talent must be invested—some disputes can require years of effort from key managers. This is talent that could otherwise be managing projects and the business. And there is the risk of the outcome itself—the disputed amounts may or may not be recovered. The approach taken here is to avoid proactively the circumstances that lead to disputes in the first place—to avoid the otherwise unanticipated impacts of changes and the surprise cost and schedule project overruns that precipitate disputes. Although it is impossible to place a number on the value of avoided disputes, it is a benefit that Fluor values highly. As a result of using the Change Impact Assessment model, the company is achieving better project outcomes and lowered costs for clients, as well as reducing costly disputes, with less diversion of key talent, and, most important above all, sustaining better long-term relations with clients.

Overwhelmingly positive client reaction and industry distinguishing capability

An unexpected benefit has been the extremely positive reaction among Fluor's clients. In the first months of piloting the work, some expressed a concern that clients would see this initiative only as a means of identifying more costs. The experience in fact shows just the opposite—clients recognize that the use of the system promotes proactive informed decisions, impact mitigation, and thus lower costs and improved performance. Indeed, over 100 presentations have been given to senior client personnel. Client endorsement is near universal, and positive without exception when discussed early in the project's life cycle. In fact, the CIA capability is now being viewed as a distinguishing source of advantage in a global market that is increasingly focused on reducing costs.

There is now substantial interest within the industry, among Fluor's competitors and project partners. Fluor is supporting that interest in the use of this new approach to change impact management through industry groups such as the Engineering and Construction Risk Institute.

Quantitative business benefits: higher revenues and lower costs for Fluor and clients

The Change Impact Assessment system is now the standard approach for evaluating change at Fluor. In every year since the first project implementation, the number of implementations has doubled. We believe this reflects not only the growing understanding of the importance of change impact management, but also the visible business successes in these early applications of the method. We have emphasized throughout this paper the better insight and improved management that this effort

has brought. What has this new insight done quantitatively to improve the performance of projects and the business?

One area of quantitative benefit is obvious. By use of this method, some costs are quantified that would not otherwise be identified. In that role, use of the system across many projects has yielded improved bottom-line performance for Fluor and its clients.

In the discussion surrounding Figure 4, we noted the use of the system to quantify in advance the degree of impact from different amounts and timing of changes. This has resulted in a significant business benefit to Fluor and its clients on many projects. Simply by identifying the true cost of changes in advance, many clients have chosen not to proceed with the costlier changes. The beneficial cost impact of changes avoided, of changes not undertaken, is not a number we have quantified explicitly, but is believed to have a cost-saving value in the hundreds of millions of dollars across the projects analyzed to date.

Throughout this paper, such as in the discussions surrounding Figures 6, 7, 10, and 14, we have emphasized impact mitigation through advance management action. The Change Impact Assessment system enables this via advance diagnosis, tradeoff analyses, and evaluation of multiple mitigation scenarios. In this single category, the identified mitigation cost savings to date total over \$1.3 billion.

Beyond the large quantitative savings and benefits, we have described how the use of the Change Impact Assessment system at Fluor has improved the understanding of project dynamics and change impacts throughout the company, and how it has transformed the approach to change impacts from that of reactive pricing to proactive impact avoidance. An entire generation of managers and planners has been trained in the new approach. Client reaction is strongly positive, recognizing the value for impact mitigation and significant cost reduction. Although much has been achieved to date, the impact of the system is ongoing, and the benefits continue to grow for Fluor and its clients.

Acknowledgments

The list of key contributors to the success of this work is long. Some of those at Fluor who have been instrumental include Mark Stevens, who has provided guidance ever since the first pilot work, and Bob Boyd, who has advanced the design and use of the system in Fluor. David Seaton and Luis Martinez have been active executive champions of the work, especially as advocates for its use as an aid to Fluor clients. At Cooper Associates, Hua Yang has been the lead architect and problem-solver for the system; Tom Kelly has been central to much of the training and project applications. We thank Renee Bartlett and Sheri Dreier for their invaluable aid in assembling this paper. Jim Lyneis provided insightful editorial guidance. Jim, along with former colleagues at PA Consulting, also contributed to the many years of client work that led to development of this system.

References

1. Cooper, Kenneth G. 1993. The Rework Cycle (a series of 3 articles): Why projects are mismanaged; How it really works...and reworks; Benchmarks for the project manager. *PMNETwork* February 1993 and *Project Management Journal* March 1993
2. Thomas, H. Randolph 1992. Effects of Scheduled Overtime on Labor Productivity. *Journal of Construction Engineering and Management* Vol 118 No 1 March 1992.
3. Fortune 500, Fortune Vol. 157 No. 9 May 5, 2008
4. Sterman, John D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*.
5. Lyneis, James M. and David Ford, "System Dynamics Applied to Project Management: A Survey, Assessment, and Directions for Future Research", *System Dynamics Review* Vol. 23, No. 2-3 (50th Anniversary Special Issue, Summer/Fall 2007) pp. 157-189
6. Cooper, Kenneth G. 1980. "Naval Ship Production: a claim settled and a framework built", *Interfaces* 10 (6): 20-36, December 1980

Authors

Ken Cooper is Managing Director of Cooper Associates, a management consulting firm based in Milford, NH (USA). Ken pioneered the use of system dynamics in project management, and has directed over two hundred model-based consulting engagements for clients managing major commercial and defense projects. In addition to Fluor, his clients have included senior executives of Raytheon, Boeing, MasterCard, Northrop Grumman, and more. He is an original author of the project simulation model used in the Change Impact Assessment system, and has published on the topics of project management, rework, and change impacts.

Greg Lee is Senior Vice President, Fluor Corporation. He has held numerous executive positions in both operations and sales during his 30+ years with Fluor. Greg has enterprise-wide responsibility for Fluor's Corporate Project Change Management Initiative. He created Fluor's Corporate Claims Management Group, and was Senior Vice President and Executive Director of Fluor's Global Sourcing and Supply Company. Greg led Fluor's world-wide corporate initiative and business operations for integrated natural gas and gas-to-liquids projects, is a past member of Fluor's Management Development Board, former President and Managing Director of Fluor Arabia, executive sponsor for various multi-billion dollar proposal efforts, and was Senior Director and Business Unit Manager responsible for the worldwide marketing and execution of lump-sum turnkey combined cycle projects.