System Dynamics Transforms Fluor Project and Change Management

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SYSTEM DYNAMICS TRANSFORMS FLUOR PROJECT AND CHANGE MANAGEMENT

Edward Godlewski
Vice President, Fluor Energy and Chemicals
Projects around the world
Introduction

- Fluor designs and builds many of the world’s most complex projects.
- Our primary objective: develop, execute, and maintain those capital projects on schedule, within budget, and with operational excellence.
- One of the biggest challenges throughout the engineering and construction industry is controlling project cost and schedule performance in rapidly changing conditions.
- We have implemented a simulation model-based system that has transformed our management of projects and changes.
- We tailor a System Dynamics model to each major project, and use the model to quantify and diagnose the future impacts of changing project conditions…and to test ways to avoid those future costs.
- In doing so over the first 5 years, we have identified over $800 million in savings for our company and for our clients around the world.
Fluor by the numbers

- $680 million net income on $22 billion revenue (2009)
- $26 billion backlog
- 36,000 employees worldwide
- Fluor is #1 in Fortune “Engineering, Construction” category (#111 overall)
- Engineering News-Record (ENR) ranks Fluor #1 among Top 100 Design-Build Firms and #2 among Top 400 Contractors
Peter Oosterveer
Group President, Fluor Energy and Chemicals
Gregory Lee
Senior Vice President (retired), Fluor Corporation
Consultant, Kenneth Cooper Associates
Projects routinely encounter changes from planned conditions… scope/design changes, late information, delayed decisions, schedule changes…changes that can account for 20-30% of costs.

Much of the impact of these changes occurs as “secondary” impact, which goes by many names (ripple effects, disruption, cumulative impact, productivity loss).

Whatever the label, the full cost impacts of changes are typically underestimated, under-recovered, and occur as project “surprises” later, when difficult to take preventive measures.

So what do you get when projects cost millions or 10’s of millions more than planned (and contracted)? …unhappy clients …legal disputes over cost responsibility
Two project management perspectives regarding change...

Traditionally: **Reactive**

Accept that change impacts are inevitable, estimate costs after they occur, and present claims to recover added cost.

With the new O.R.: **Proactive**

Anticipate and mitigate potential change impacts, to control their future effect on project cost and schedule...

- ... Scope additions (“increase plant capacity”) and deletions (“take some cost out”)
- ... FEED/Preliminary Engineering readiness (when to start Detailed Design)
- ... Engineering work schedules (e.g., acceleration)
- ... Construction work schedules (“get to the field early”)
- ... Supplier delays (data, designs, equipment)
- ... Staffing levels (“catch up”)
- ... Design change approvals (timing matters)
A fundamental challenge: Impacts are often widely separated in time and space from the precipitating changes.

"Project X" Labor

Changes here... ...cause impact here

Original Plan

Actual

People

Time
More challenges…

- Not *retrospective* “what happened”, but *advance* “what would happen if”
- When? – timing of the future impacts
- Why? – causation of the future impacts
- Not just construction and scope changes – also, engineering changes, information delays, even schedule changes
- One change? 1000?
- Usable broadly, quickly, accurately
Kenneth Cooper
Managing Principal, Kenneth Cooper Associates
Three-part analytical solution

1. System dynamics model of projects
2. Tools for rapidly tailoring
3. Deploying the project models to non-modelers
System Dynamics is a methodology and simulation modeling technique for analyzing complex systems. Rooted in engineering control theory, the method has been used to model and analyze companies, industries, complex projects, and more.

The fundamental principles emphasize...

**Cause-Effect**

![Diagram showing cause-effect relationship between Overtime and Productivity]

The effect of one factor on another may be *time-delayed* and *non-linear*, as with the effect of overtime on productivity.

**Feedback Loops**

![Diagram showing feedback loops among Overtime, Productivity, and Progress]

Feedback among cause-effect relationships can be corrective, or self-reinforcing. Here, more overtime usage increases progress, lowering overtime needs (corrective); but sustained overtime lowers productivity, slows progress, and thus increases the need for more overtime (self-reinforcing).
The strength and timing of cause-effect relationships are described by model equations that can simulate behavior over time, and accurately represent a project plan.

“What if” experimentation with an accurate model helps identify future impacts, and can test the effect of different actions.
Recall “Project X”

What we need is the ability to foresee and avoid… but first we need to understand…

[Graph showing the comparison between the original plan and actual progress over time.]
So, what happened on “Project X”?

\[
WorkToBeDone(t + dt) = WorkToBeDone(t) - Progress(t) \times dt
\]

\[
Progress(t) = People(t) \times Productivity(t)
\]

\[
WorkDone(t + dt) = WorkDone(t) + Progress(t) \times dt
\]

“Our productivity was impacted.”
So, what happened on “Project X”?  

Work ‘done’…and done and done and done…

![Diagram showing the issuance of drawings for different revisions over time.](image-url)
So we added ‘rework’ to the model:

So, what happened on “Project X”?
A better way of looking at projects and secondary impacts

People  Productivity  Quality

Work To Be Done  →  Work Done

Known Rework  →  Undiscovered Rework

Rework  Discovery

Progress
A story from one project, experienced by many…

Have you seen any of these next conditions on a project…?
“The customer added (+) and changed (∆) work so much, we staffed up more.”
“We used lots of overtime and had to hire in tight markets.”
“Less skilled new hires also needed more supervision.”
“Rework caused more rework.”
“Under pressure, morale suffered.”

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.

These inter-related factors are coded in the model equations, to produce a time-stepping simulation of the project.
Equations: Rework Cycle

\[ \text{WorkToBeDone}(t + dt) = \text{WorkToBeDone}(t) - \text{Progress}(t) \times dt \]

\[ \text{WorkDone}(t + dt) = \text{WorkDone}(t) + \text{Quality}(t) \times \text{Progress}(t) \times dt \]

\[ \text{UndiscoveredRework}(t + dt) = \text{UndiscoveredRework}(t) \]
\[ + (1 - \text{Quality}(t)) \times \text{Progress}(t) \times dt - \text{ReworkDiscovery}(t) \times dt \]

\[ \text{KnownRework}(t + dt) = \text{KnownRework}(t) \]
\[ + \text{ReworkDiscovery}(t) \times dt - \text{ReworkCorrection}(t) \times dt \]

\[ \text{Progress}(t) = \text{StaffOnProject}(t) \times \text{Productivity}(t) \]

\[ \text{ReworkDiscovery}(t) = \frac{\text{UndiscoveredRework}(t)}{\text{ReworkDiscoveryTime}(t)} \]
Equations: Productivity

\[ \text{Productivity}(t) = \text{ProductivityNorm} \]
\[ \times \text{Effect on Productivity}(\text{influence}_1(t)) \]
\[ \ldots \]
\[ \times \text{Effect on Productivity}(\text{influence}_n(t)) \]

Effect on productivity from each influence is a monotonic function of the given influence. For example, productivity decreases as overtime use increases (see the graph below).
Equations: Staffing

\[ \text{StaffOnProject}(t) = \text{Min}(\text{StaffRequested}(t), \text{StaffAvailable}(t)) \]

\[ \text{StaffRequested}(t) \\
= (\text{ExpectedHoursAtCompletion}(t) - \text{HoursExpendedToDate}(t)) \\
/ (\text{Scheduled Time Remaining}(t) \times \text{NormalStaffWorkHours}) \]

\[ \text{ExpectedHoursAtCompletion}(t) \\
= \text{HoursExpendedToDate}(t) / \text{PerceivedProgress}(t) \]

\[ \text{StaffAvailable}(t + dt) = \text{StaffAvailable}(t) + (\text{Hiring}(t) - \text{Turnover}(t)) \times dt \]

\[ \text{Hiring}(t) = \text{Max}(0, \\
(\text{StaffRequested}(t) - \text{StaffAvailable}(t)) / \text{HiringDelay} + \text{ExpectedTurnover}(t)) \]
Three-part analytical solution

1. System dynamics model of projects
   - Cause/effect
   - Feedback loops
   - Time delayed and non-linear effects

2. Tools for rapidly tailoring

3. Deploying the project models to non-modelers
How to get to a tailored project model...

Several new system steps were required

Core Model Structure

Staffing

Progress

Tailored Project Model & Base Simulation

Several new system steps were required
Several new system steps were required
Interface embeds project plans as inputs

**PLAN:**

- **Start Construction Month 10**
- **22 months duration**
- **2.5M Craft hours**
Interface combines reference standards, global surveys, and project-specific productivity conditions.

Set project specific productivity conditions to match those assumed in project plan (benchmarked against industry reference or Fluor office standard).

Periodic global surveys update office standard productivity conditions, tapping 40,000 person years of project experience.
Hill-climbing algorithms guide tailoring of model to simulate the project plan
Tailoring converges model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity…

Initialize
- Productivity norm
- Staffing timing
- Productivity influence_1
- ...
- Productivity influence_n

Simulate

Start

Adjust

Simulated Cum Effort
Planned Cum Effort < Tolerance Deviation?
Yes

Simulated Peak Time
Planned Peak Time < Tolerance Deviation?
Yes

Productivity
Planned Max Impacts(1)
Sim Max Impacts(1) < Tolerance Deviation?
Yes

Productivity
Planned Max Impacts(n)
Sim Max Impacts(n) < Tolerance Deviation?
Yes

End

Experience

Plan

Tailored Simulation

Progress

Plan

Tailored Simulation

Staffing

Plan

Tailored Simulation
Tailoring converges model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity…
Tailoring converges model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity...

**Initialize**
- Productivity norm
- Staffing timing
- Productivity influence_1
- ...
- Productivity influence_n

**Simulate**

**Start**

**Adjust**

**Simulated Cum Effort**

\[
\frac{\text{Simulated Cum Effort}}{\text{Planned Cum Effort}} - 1 < \text{Tolerance Deviation}?
\]

**Simulated Peak Time**

\[
\frac{\text{Simulated Peak Time}}{\text{Planned Peak Time}} - 1 < \text{Tolerance Deviation}?
\]

**Productivity**

\[
\frac{\text{Planned Max Impacts}(1)}{\text{Sim Max Impacts}(1)} - 1 < \text{Tolerance Deviation}?
\]

**Productivity**

\[
\frac{\text{Planned Max Impacts}(n)}{\text{Sim Max Impacts}(n)} - 1 < \text{Tolerance Deviation}?
\]

**End**

**Plan**

**Tailored Simulation**

**Experience**

**Progress**

**Staffing**
Tailoring converges model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity...
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Tailoring converges model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity…
(Three-part analytical solution)

1. System dynamics model of projects
   - Cause/effect
   - Feedback loops
   - Time delayed and non-linear effects

2. Tools for rapidly tailoring
   - Embed company reference and industry standards
   - Embed project plans as part of model input
   - Converge model to simulate correctly amounts and timing of staffing, progress, productivity, effects on productivity

3. Deploying the project models to non-modelers
The project model user specifies changes to be tested via the system interface.

### Change Impact Avoidance System (CIA v 12.7)

<table>
<thead>
<tr>
<th>Direct Impact on Engineering from Changes</th>
<th>Group 1 changes, events</th>
<th>Group 2 changes, events</th>
<th>Group 3 changes, events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly added engineering hours:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount (hours)</td>
<td>4000</td>
<td>5000</td>
<td>6000</td>
</tr>
<tr>
<td>Timing (months after detailed engineering start):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>End</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Design technical content affected by the changes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount (%)</td>
<td>7</td>
<td>9</td>
<td>13</td>
</tr>
</tbody>
</table>

Input foreseeable direct impacts (e.g. added work hours, change timing, design content affected)
The system provides summary reports and automated cause-effect diagnostics.

This project cost grows 30% with 12% added hours of direct change impact (1.5 secondary impact ratio); changing engineering is the biggest driver of secondary impact in construction.
Number of applications grew rapidly after the second year...
Testing “changed conditions” on projects may mean changed schedules

One real example of benefits…

For a client to whom cost was a high priority, “what if” analyses conducted before the project began anticipated the project performance under different contemplated schedules…

![Graph showing Engineering Labor over time with shaded area indicating earlier schedule targets require increased labor]
Diagnostics help explain why

And because of the increased late revisions, only 2/3 of the attempted acceleration would be achieved…
Based on the analyses, this cost-conscious client chose a later schedule, to reduce costs.

This is the example that Group President Peter Oosterver ver mentioned... the $23 million savings achieved by rescheduling.

Dozens of other projects have benefited from the same type of analyses as well...
100+ Proactive uses of system dynamics model and project simulation system

Examples...

Scope

Additions...

...(the classic case) Several changes on a mining project added scope and reduced productivity. Model used to analyze and recover $10 million of future impact not otherwise quantifiable. Changes and full cost amount agreed, and a cost-saving schedule adjustment identified, saving an additional $2 million.
Quantitative benefits: savings achieved for Fluor and our clients bottom-line

100+ Proactive uses of system dynamics model and project simulation system

Examples...

Preliminary Engineering Readiness...

...Analyses of tightly scheduled "turnaround" project identified large productivity gains achievable with different overlap of adjacent engineering phases. Work rescheduled accordingly, saving $34 million.
100+ Proactive uses of system dynamics model and project simulation system

Examples...

Staffing Levels...  **Client asked Fluor to evaluate cost of accelerating the staffing buildup they requested on engineering a refinery project. Model quantified cost, plan changed accordingly, saving $25 million.**
100+ Proactive uses of system dynamics model and project simulation system

Examples...

**Design change approvals...**

...Project team redesigned process of reviewing changes to speed their definition and approval, based on model's what-if analyses of mitigation value, saving $10 million.
100+ Proactive uses of system dynamics model and project simulation system

Examples...

**Construction work schedules**...

...Small European project was running in parallel with a similar project, both encountering many changes. One project manager employed the model to choose when to "go to the field" (start construction). Manager credits model findings with this project being "much smoother", and saving $1 million.

...On a change-filled project, Fluor's client sought lower cost. Based on model's analyses of change impacts under different schedule scenarios, client implemented a new construction schedule, saving $23 million.
100+ proactive uses of system dynamics model and project simulation system with quantified impact on these and dozens of other projects since 2006…

Greater than $840 million in savings

Designation by Engineering Construction Risk Institute (ECRI) as “Industry Best Practice”
Thank you for the opportunity to share with you the Fluor story.
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