December 2007

Implications of Complexity Theory on Real Option Analysis in IT Portfolio Management

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Abstract:

In IT Portfolio Management, Real Option Analysis (ROA) and Discounted Cash Flow (DCF) analysis are often used to place a quantitative value on an IT investment. ROA is theoretically superior to DCF analysis because ROA specifically attempts to account for managerial flexibility or the ability of management to adjust to a changing situation. However, while DCF analysis has been criticized as undervaluing IT projects, ROA has been criticized as overvaluing them.

One possible explanation for an upward bias in ROA is that it often incorrectly assumes that managers will be able to make follow-on investments to an IT project if that project is successful, (i.e. Growth options). Drawing from complexity theory and using project data from three large private organizations in the Mid-West we found that there was a log-linear relationship between the number of projects and SDLC phase. The implication is that organizations primarily using internal IT resources are only able to develop a small number of late stage projects at a time.

This in turn has important implications for Outsourcing, IT project portfolio management, and ROA. Specifically many growth options used in calculating project value in ROA may be unrealistic given the limited resources of private organizations.

Keywords: IT Portfolio Management, Complexity Theory, Real Options Analysis

Introduction

One problem that continually faces CIO's and IT managers is how to select and prioritize IT projects that become available to the organization. IT project portfolios can contain hundreds of potential projects, however because of budgeting and resource constraints not all can typically be pursued. In order to rank projects according to priority, firms typically use Discounted Cash Flow (DCF) analysis to determine Net Present Values (NPV). Projects with positive NPVs are funded subject to the firm's resource constraints. However, DCF ignores managerial flexibility, for example the ability of managers to cancel a failing project or to expand a successful one. Real Options Analysis (ROA) is an alternative way to value projects that attempts to explicitly place a value on this managerial flexibility to adapt.

One type of Real Option that is often embedded in IT projects is called a Growth Option. Growth options are options to build a new project on top of a successful project. For example, if a company successfully installs a Unix Server, it can then potentially build an e-Commerce Web site on an Apache Server. Thus, in calculating the potential value of the Unix Server Project, the potential value of the e-Commerce Website should be considered. However, is it realistic to assume that the firm will have the resources to build the follow-on project, in this case the e-Commerce Website?

Complexity theory is often used to explain the relationship between such diverse things as the frequency and severity of earthquakes, the frequency and severity of floods, the distribution of human populations, and the fluctuations of commodity prices over time. A key characteristic of complexity theory is that the number and magnitude of events follow a log-log or log-linear pattern. Inspired by an example by Peter Grassberger (Bak, 1996, pg. 54-55) on the potential use of complexity theory in organizations, we discovered that for several large organizations in the Mid West the number of projects in any given stage of the SDLC followed such a, pattern indicating that they may be complex systems. That is, there were far more projects in the early phases of the SDLC than in the later phases, in one case by a factor of almost a hundred. This has major implications to firms using Real Option Analysis (ROA), particularly in firms that are depending on embedded growth options to calculate project values.

The rest of this paper is organized as follows. First, the background of this research is given in order to place it within the proper frame of reference. Second, a short explanation of Real Option Analysis is given. Although ROA is not the substantial focus of this work per se, the implications of this research are. Third, a short literature review of the major works on complexity theory is given, followed by a rationale for why complexity theory may be pertinent to IT Portfolio Management. Fourth, information regarding our hypotheses, model, data and results are presented. Lastly implications and areas for further study are discussed.

Background

At the behest of several large private organizations our team has been developing a staged portfolio management methodology to assist executives and IT managers in selecting and prioritizing their IT project portfolios. Our methodology is a strategy focused methodology that is based on and extends Kaplan and Norton's work with Strategy Maps and is currently being explored by IT teams within several large Fortune 500 companies. Although this paper will focus on just a small part of our work, it is briefly summarized here in order to properly frame this research. The stages in our methodology are:

Stage 1: Develop a Strategy Map (Kaplan and Norton, 2002) for the organization that visually shows how proposed IT investments link to the strategic goals of the firm. Investments that are obviously not linked to company strategy are usually pruned during this stage from further consideration.

Stage 2: Develop Aggregate Project Maps that visually show how the potential IT investments balance the tradeoff between Business Criticality and Technological Maturity. Business Criticality scores represent how much a particular project aligns with firm strategy, while Technological Maturity scores represent how mature the technology needed to produce the project is within the firm -- in the opinion of the firm's executives. These scores are developed using scoring models that are unique to the firm, and are based on the knowledge and experience of the firm's IT management team. Those projects that obviously do not give a suitable return on this tradeoff are usually dropped at this stage. Although Aggregate Project Maps are not a focus of this article, a simple example for one section of an IT department is shown below in Figure 1.

Stage 3: Rank the remaining IT projects quantitatively using several different criteria, so that they can be prioritized for investment. Currently we are using several different methods to rank the IT projects.

A. Projects ranked by risk category. Different firms have different tolerances for risk, which may change over time. Certain projects may simply be too risky to be palatable for a firm.

B. Projects ranked by Criticality vs. Technological Maturity efficiency. As can be seen visually in Figure 1, some projects give a better return on criticality vs. maturity than others. We also use some traditional quantitative techniques, i.e. portfolio optimization to identify and prioritize efficient IT investments.

C. Projects ranked using Real Option Analysis.

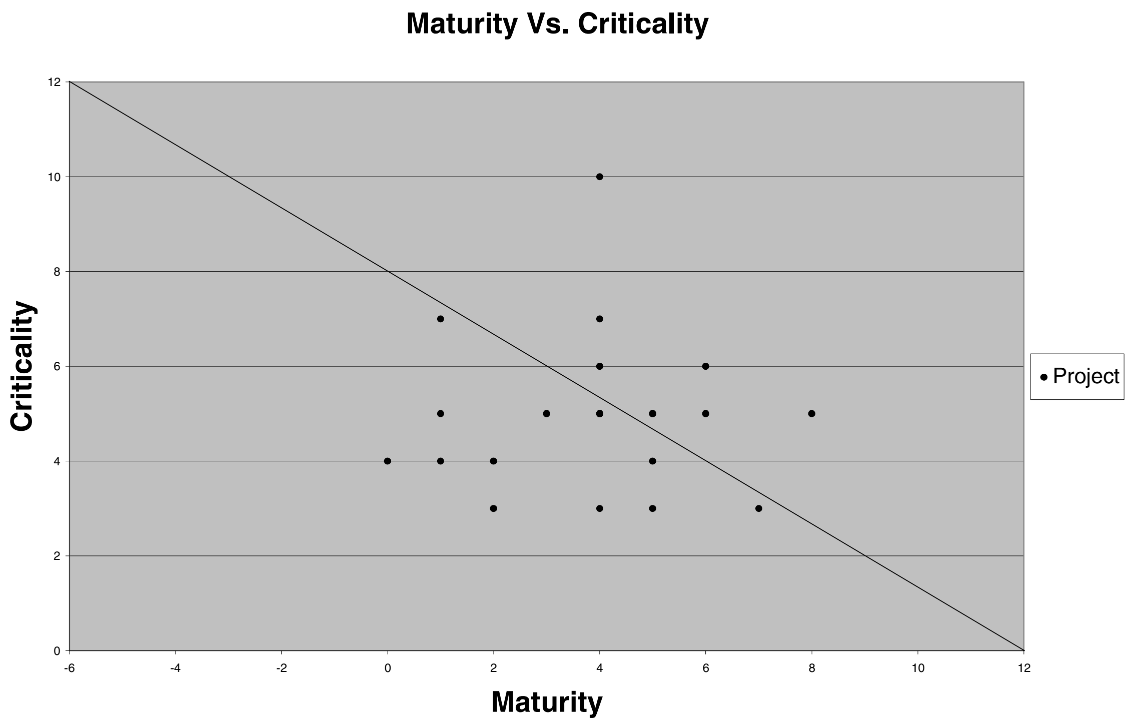

Figure 1: Example of an Aggregate Project Map

Real Option Analysis

As mentioned above, IT projects can be ranked using traditional Discounted Cash Flow techniques, which attempt to put a quantitative value on IT investments. One weakness of this technique is that it ignores the managerial flexibility to adapt to changing situations. Instead DCF usually calculates a single value based on the current information available and firms invest in all projects with a positive NPV. The difficulty in using this method is that projections of cash flows are based on assumptions that often change. Also, in order to reflect the uncertain nature of IT investments cash flows are typically discounted at rates reflecting the high variance inherent in technology investments. Thus, the calculated net present values of such projects are easily undervalued.

ROA attempts to account for managerial flexibility or the ability of management to adjust to a changing situation. As a simple example, a manager faced with the decision to invest in Betamax or VHS equipment in the early 1980's would be greatly challenged using DCF analysis because at that time it was not clear which standard would eventually dominate. Because DCF analysis gives a one-time answer both investments might have a calculated negative NPV. However, this standard "go/no go" or "yes/no" decision process can be refined using Real Options Analysis to give a greater range of choices for investment, "invest now", "invest never", or in this example "defer investment" until a standard has been chosen by the market. In a sense the value of a project can be thought of as:

Project Value = NPV + the value of the real options associated with the investment

The types of options commonly associated with IT investments are listed in Table 1 (Benaroch, 2002). By specifically embedding and accounting for real options in IT investments, managers can increase the calculated value of IT projects using either the Black-Scholes or Binomial Option models.

However, one issue that became apparent in our work was that ROA has the potential to greatly over-value a project when large parts of its value are derived from staged, scale up, and particularly growth options. Simply put, firms simply do not appear to have the capability to invest in all of the projects they determine to be valuable.

Table 1: Common Option Types

Option	Description
Defer	The option to delay investment until more information can be learned about the project, such as costs, prices, demand etc.
Stage	The option to build a project in stages, where investment can be delayed or even killed if the environment changes.
Explore	The option to use a pilot program to better learn about a project before initiating it on a full-scale basis.
Scale	The option to increase or decrease the scale of a project depending upon its success.
Abandon	The option to kill a project if it goes badly.
Outsource	The option to subcontract a project or part of a project to shift some downside risks to a third party.
Lease	The option to lease some resources to shift some downside risks to a third party.
Growth	A set of projects where the value of earlier projects depends largely on investments in additional projects, i.e. an infrastructure investment that assumes follow-on investments will be made using that infrastructure.
Compound	A combination of the above options in one project.

Complexity Theory

Complexity theory has its roots in the natural sciences and Darwin's the "Origin of the Species", which describes the process of natural selection, is often given as its starting point. No centralized authority is assumed to guide evolution under Darwin's theories; it is self-organizing (Darwin, 1859). Likewise, the laws of thermodynamics state that left alone closed systems tend towards higher entropy and equilibrium. However, if a system is an open system and even a small amount of energy is absorbed from outside then the system will tend to self-organize, and not reach equilibrium. As a simple example, people eat food and therefore survive. If a person did not absorb energy through food, they would die (Prigogine et al., 1984).

Herbert Simon (1996) is often credited with beginning the study of complexity in organizations while John Holland has produced two fundamental works in this area, "Adaptation in Natural and Artificial Systems" (1992) and "Hidden Order: how adaptation builds complexity" (1996). The latter is particularly important because modeling interacting agents in business is a major research area within complexity theory. Basically multiple agents interacting using simple rules can produce surprisingly complex behavior in a system, for example the "Bullwhip Effect" within supply chains.

Per Bak (1996) went further and suggested that organizations may themselves be open, self-organized, critical and complex systems. Self-organized criticality is the idea that systems naturally slowly evolve to a critical state which periodically experience radical change. The classic example is the sand pile model. If grains of sand are continuously piled on a flat surface they will build up into a hill which over time will experience many small avalanches and a few large avalanches.

The initial impetus for this work initially came from this idea of self-organized criticality. Complexity theory suggests that such systems actually follow predictable patterns. These patterns are exhibited by many wide ranging seemingly unrelated phenomenon such as earthquakes, river floods, city sizes, extinctions and commodity price fluctuations. These phenomena can all be classified as "complex systems" and generally follow power law distributions where the size of an event is proportional to its frequency, $N=1/f$. For example, earthquakes follow the Gutenberg-Richter model. That is, the number of large earthquakes is exponentially smaller than the number of large ones.

This pattern is predictable but stochastic, meaning that exactly when large earthquakes or commodity price fluctuations will occur remains unpredictable, but the number of earthquakes per year is very predictable, much like flipping a coin. That is, given many flips of a fair coin it is possible to predict that roughly half will be heads, yet it is not possible to predict what the next flip will be. Earthquakes, commodity prices and many other systems in nature follow such stochastic behavior, but with a $1/f$ pattern as opposed to the simple Bernoulli pattern exhibited by a coin.

Peter Grassberger suggested that concepts from complexity might also help explain organizational behavior, in particular the interaction between different employees and groups within a firm (Bak, 1996, pg. 54-55). Although not universally agreed upon, the general characteristics of complex systems (Anderson, 1999, pg. 3-15;Kelley and Allison, 1998; Bak, 1996, pg. 1-32) and how they might relate to IT are:

- ***Complex systems are open:*** Unlike traditional models used in many parts of economics and business, complex systems are open systems; they are not in equilibrium. In project management, projects are not managed in a vacuum. Current events, corporate politics, and even other projects will all influence the life cycle of a project.
- ***Complex systems can be nested:*** Complex systems are naturally made up of many parts, some of which may be complex systems themselves. In terms of an IT project, a project may be worked on by many different departments or teams each of which may themselves be complex systems. Also, one major project may consist of many sub-projects, such as an SAP installation and its many sub-components.
- ***Complex systems have a history:*** In neo-classical economics, firms are often considered to be homogeneous such as in perfect competition. However, in complex systems, much like in the Resource Based View of the firm (Wernerfelt, 1984; Barney, 1986), this is specifically not considered to be true. The most important organizational resources may be unique, and a firm's future may be quite sensitive to initial conditions. In terms of project management some IT departments may have built strong Java skills, others may have strong C++ skills, and still others may have strong design skills. These unique skills and experiences are developed over time and affect a firm's future choices.
- ***Complex systems emerge:*** Complex systems are made up of many agents following simple rules that may produce complex interactions. Therefore, studying the component parts of a complex system does not necessarily explain the overall behaviour of the system. In project management a particular manager and a particular development team may both work well separately, but they may not get along when working together. Likewise, an IT infrastructure project that by itself has a low NPV may enable the firm to make several follow-up investments with much higher NPV's.
- ***Relationships are often non-linear:*** Unlike in simple systems, in complex systems a small input may have no effect, a proportional effect, or an extraordinary effect on outcomes. This is a common experience in IT where a new technology may completely fail despite huge investments or may result in supernormal profits using just minimal initial investments.
- ***Relationships contain feedback loops:*** Complex systems often have feedback loops which reinforce themselves. In IT, a firm that successfully invests in a particular technology will often continue to invest in similar technologies, which leads to more success and additional investments.
- ***Complex systems exhibit self-organized criticality:*** Complex systems often experience a long slow evolution to a critical state followed by a rapid very large change (Bak, 1997). In terms of a project one way this would be exhibited is by a change from one phase of the SDLC to another phase. This is very similar in concept to punctuated equilibrium (Orlikowski, 1996). For example, a project that replaces an old 10 base T Ethernet network may languish at the design stage of the SDLC for years until network congestion eventually compels the organization to green light the project and move it to the development stage. When the new network is installed it will likely be a significantly faster network, which in turn may significantly speed up other applications that depend on network bandwidth.

Model

Project management as taught in the classroom often follows the traditional System Design Life Cycle (SDLC). Whether there are four, five, six, or seven phases in the model depends largely on the particular book used and the organization teaching it. However, two characteristics these models tend to have in common are that:

a.) Later phases in the SDLC tend to require much greater resources and organizational commitment than earlier phases.

b.) These models tend to neglect outside influences and focus on the project as a separate unit from the overall organization.

Because we believe that IT portfolio management is actually a dynamic complex system which exhibits many of the characteristics discussed in the prior section, we hypothesize that within an IT portfolio of projects, the number of IT projects by SDLC phase will follow a log-linear model. This is consistent with Grassberger's suggestion about using complexity theory for organizations. Although power laws typically suggest a log-log relationship, a semi-log relationship is predicted because the time and resources required in each stage is assumed to be exponentially greater than the stage immediately prior. For example, if the SDLC model used is that shown in Table 2, then it is assumed in our model that the time, money and resources used in Analysis are exponentially larger than those used in the Feasibility Study. This makes sense as the number of people affected in each phase of a project typically grows by phase. That is, the number of end users is usually greater than the number of developers which is usually greater than the number of system architects.

Table 2: Phases in the SDLC

Phase	Name
1	Feasibility Study
2	Analysis
3	Design
4	Development
5	Testing
6	Implementation

Specifically we hypothesize that:

$\text{Ln}(y) = \beta x + c$

where y = Number of projects at that phase, and x is SDLC project phase, or

Ln(number of projects) = β(project phase) + c

Our initial assumption was that Ln(y) would follow a normal distribution, but upon further research, consistent with Agresti, it was thought that the dependent variable in the above model might be better fitted by a Poisson distribution (Agresti, 1996, pg. 71-102). This is known as the identity link for a generalized linear model that assumes a log-linear relationship. In actual fact, using the Poisson distribution made only a marginal improvement in the fit of the model, but the Poisson distribution is the traditional statistical technique for modeling count data, and specifically assumes that there cannot be a negative count..

Data

Data was obtained from three large organizations located in the Midwest. Two were IT project portfolios from sections of Fortune 500 companies. One was an IT project Portfolio from an educational organization. The data obtained is listed in Tables 3a, 3b, and 3c.

Organization 1 is a division of a large Fortune 500 company. Generally the time horizons of these projects are less than three years[1], usually a year or less. Organization 2 is from an IT team that is focusing on innovation and new technology also within a large Fortune 500 company. These projects are more speculative in nature than those in Organization 1; however they follow a staged lifecycle. The major difference between these two portfolios is that all four stages of Organization 2's portfolio can be thought of as being subsets of the Pre-Initiate Phase of Organization 1. That is, when projects in Organization 2 reach Phase 4 they will graduate to what would be considered the Initiate and Requirements phases of Organization 1. Organization 3 is a University in the Midwest. The stages are listed in the table as they are used within the organization. These projects are more similar to Organization 1 in that they are likely to be implemented over the next three years.

As can be seen the number of projects and the SDLC methodology used in the three organizations is somewhat different. It also should be noted that the project sizes and resource requirements needed is also very heterogeneous both within and between the three organizations' project portfolios. Dollar amounts for each project ranges from thousands to millions of dollars particularly in Organization 1. This is not necessarily a problem using complexity theory, as one characteristic of a complex system is that they may be scale free much like fractals found in the fjords of Norway are scale free (Mandelbrot, 1983; Bak, 1997). That is, although the projects may appear to be heterogeneous, the assumption is they follow similar rules because a project is a project no matter what its size.

[1] The Initiate and Requirements phases of Organization 1 were combined because they were thought to basically map to what is usually referred to as the Analysis phase in the traditional SDLC. Also, Organization 1 considered three years to be long-term IT projects. Most projects were budgeted for one year or less.

Table 3a: Data for Organization 1: Division of a Large Fortune 500 Firm

Phase Name	Number of Projects	ln(number of projects)
Pre-Initiate	398	5.986452
Initiate + Requirements	121	4.795791
Design	35	3.555348
Build/Test	15	2.70805
Deploy	6	1.791759
In production	4	1.386294

Table 3b: Data for Organization 2: IT Innovation Team of a Large Fortune 500 Firm

Phase Name	Number of Projects	ln(number of projects)
1	19	2.944439
2	10	2.302585
3	3	1.098612
4	1	0

Table 3c: Data for Organization 3: IT Department of a University in the Mid-West

Phase Name	Number of Projects	ln(number of projects)
requested	15	2.70805
seeking funding	9	2.197225
funded active	6	1.791759
initiated	4	1.386294
closed	2	0.693147

Results

The data was regressed using both Log-Linear Poisson regression and Log-Linear Normal regression. Our original model assumed a normal distribution for the dependent variable; however after researching Agresti we determined that a Poisson distribution was also applicable (Agresti, 1996, pg. 71-102). Both models fit well, as shown by the plotted data below, however the Poisson distribution fit slightly better, particularly in the later phases of the SDLC. The regression statistics below are those that assume a Poisson distribution. The Log-Likelihood ratio tests and Wald statistics are all significant, as are all the intercepts and coefficients for the variable Phase. The regression results are shown in Tables 4a, 4b and 4c, with the predicted vs. actual values shown in Figures 2, 3, and 4.

Table 4a: Poisson Regression Results for Organization 1				
Criterion	**DF**	**Value**	**Value/DF**	**PR > ChiSQ**
Deviance	4	5.2226	1.3056	-
Pearson Chi-Square	4	6.4797	1.6199	-
Wald Statistic	1	490.07	-	< .0001
Log Liklihood	-	2562.6409	-	-
Log-Liklihood Ratio	1	991.75	-	< .0001

Table 4b: Poisson Regression Results for Organization 1							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95 % Confidence Limits**		**Chi-Square**	**Pr > Chi-Square**
Intercept	1	7.0733	0.0852	6.9063	7.2404	6887.04	<.0001
Phase	1	-1.1104	0.0502	-1.2087	-1.0121	490.07	<.0001

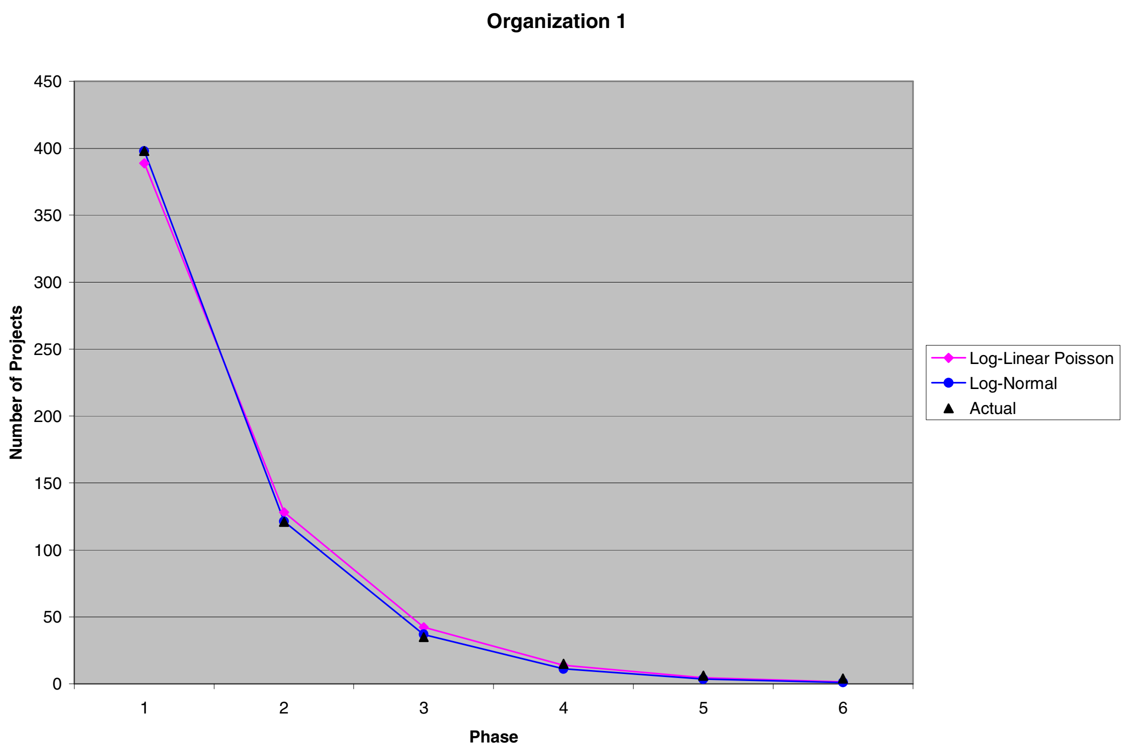

Figure 2: Fitted Data for Organization 1

Table 5a: Poisson Regression Results for Organization 2				
Criterion	**DF**	**Value**	**Value/DF**	**PR > ChiSQ**
Deviance	2	0.5748	0.2874	-
Pearson Chi-Square	2	0.5882	0.2941	-
Wald Statistic	1	18.419602	-	< .0001
Log Liklihood	-	48.9786	-	-
Log-Liklihood Ratio	1	24.68	-	< .0001

Table 5b: Poisson Regression Results for Organization 2							
Parameter	DF	Estimate	Standard Error	Wald 95 % Confidence Limits		Chi-Square	Pr > Chi-Square
Intercept	1	3.8956	0.3721	3.1663	4.6248	109.62	<.0001
Phase	1	-0.8957	0.2087	-1.3047	-0.4867	18.42	<.0001

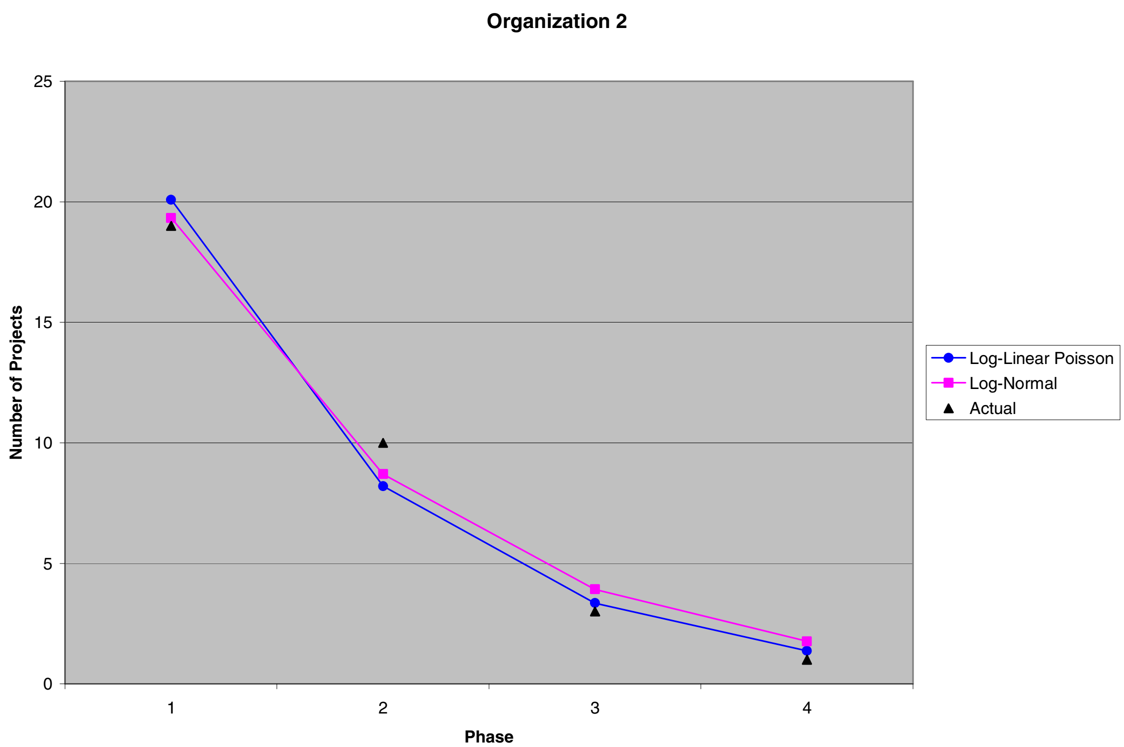

Figure 3: Fitted Data for Organization 2

Table 6a: Poisson Regression Results for Organization 3				
Criterion	**DF**	**Value**	**Value/DF**	**PR > ChiSQ**
Deviance	3	0.0859	0.0286	-
Pearson Chi-Square	3	0.08555	0.0285	-
Wald Statistic	1	12.195495	-	0.0005
Log Liklihood	-	42.0348	-	-
Log-Liklihood Ratio	1	13.94	-	< .0002

Table 6b: Poisson Regression Results for Organization 3							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95 % Confidence Limits**		**Chi-Square**	**Pr > Chi-Square**
Intercept	1	3.1739	0.3329	2.5214	3.8263	90.9	<.0001
Phase	1	-0.4704	0.1347	-0.7345	-0.2064	12.19	0.0005

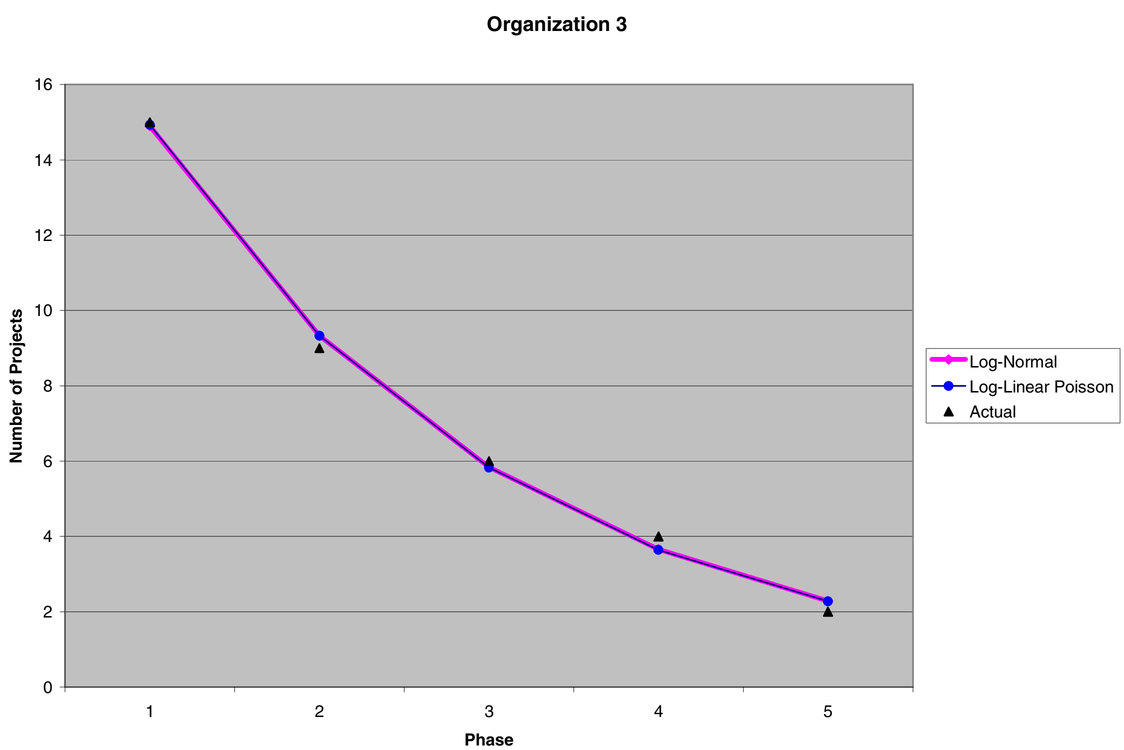

Figure 4: Fitted Data for Organization 3

Discussion

As can be seen from the graphs and regression statistics given above, the model fit surprisingly well given the heterogeneous nature of the projects both between and within firms. However, this is consistent with the idea of Complexity Theory, which would predict that all such complex systems would follow a similar pattern. The results seem to indicate that firms are simply unable to move all of the projects that they would like to later phases of the SDLC. As can be seen even the largest organization was unable to be in the final phases of the SDLC for more than a half dozen projects.

The idea that a firm is limited by its internal resources is an old one. Edith Penrose viewed the firm as a "collection of productive resources" (Penrose, 1959 pg. 24), and argued that a scarcity of managerial talent effectively limits the growth of a firm. Similarly, the Resource Based View (RBV) of the firm suggests that firms can only develop a competitive advantage using resources that are valuable, imperfectly imitable, imperfectly substitutable and above all rare (Wernerfelt, 1984). This limitation, often imposed by a scarcity of managerial talent, is especially important because the managers in all of the organizations in question supervised multiple projects.

While a drop off in the number of projects in each phase is not surprising, (traditional SDLC courses teach that projects can be and should be cancelled), what is surprising is that they seem to drop off very sharply and in a very predictable log-linear way. This has important implications for Real Options Analysis, notably:

- If these firms are indeed complex systems, as the results seem to indicate, then it is not generally possible to increase project throughput without changing the system. One characteristic of complex systems is that they exhibit such log-linear relationships and these are generally persistent over time (Bak, 1997).

- Calculated project values that depend on growth or scale up options may be significantly overvalued. It appears that even the largest firms are limited in the number of projects they finish at one time, and therefore the assumption that a large portion of a project's value will come from future follow-on projects may be untenable.

- In addition, the severe drop off in projects in the early phases could indicate that firms place a lot of value in abandonment and/or deferment options – basically trying out a bunch of speculative projects knowing that many will prove unprofitable and be cancelled.

Finally, we have some preliminary evidence, which will be used in a follow-on research project that suggests that organizations that primarily outsource their work, rather than use in-house resources do not face a log-linear decrease in the number of projects by phase. Such organizations are not as complex in the sense that their IT projects are handled by other organizations. When these results were discussed with the CIO of Organization 1, he was somewhat aware of this phenomenon, and explained that his firm was able to produce projects cheaper in-house, and was willing to put up with a lower project completion rate in exchange for lower cost outlays.

Future Research

While the above results are interesting, they leave many important questions unanswered. Why does the number of projects drop off the way it does? Does management realize the trend and purposely pursue many abandonment and deferment options? Do more homogeneous mixtures of projects follow the same trend? Does the slope of the curves have any particular managerial significance? Does the trend hold across other firms and industries? And finally, does the industry or sector the organization is in significantly affect the trend?

Our preliminary investigations on this last point suggest that it does, and in some cases greatly, however it is beyond the scope of this paper. Further information regarding our methodology in IT Portfolio management is available upon request in the form of a working paper.

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