INVESTIGATION OF IMPACTS OF DYNAMIC CONCURRENCE ON DEVELOPMENT PROJECT MANAGEABILITY

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ABSTRACT

Shrinking cycle time with concurrent engineering can make projects more difficult to manage. However, the extent, nature and conditions of the causal relationship between concurrence and manageability are not well understood. This study uses Degree of Concurrence and Degree of Concurrence Relationship Curvature as two measurements of dynamic concurrence based on Process Concurrence Relationship, an improved tool for describing and modeling concurrence, and uses the standard deviation of Process Work Queue Acceleration as Manageability Index to model project manageability. Single-phase development process model is applied as a data collection tool to investigate the causal relationship between concurrence and manageability. Two hypotheses were developed to test the causal relationship separately with the two different experiments - Linear and Nonlinear. The study finds a significant inverse relationship between degree of concurrence and project manageability with linear concurrence relationship. When the concurrence relationship was changed from linear to nonlinear the relationship became quite unexpected. The results improve the understanding of the causal relationship between dynamic concurrence and manageability.

Keywords: Project Management, System Dynamics, Concurrence, Project Manageability, Degree of Concurrence, Degree of Concurrence Relationship Curvature, and Process Work Queue

INTRODUCTION

Research and experience confirm that companies with superior long-term performance are those that deliver successful innovation. Today, leading companies derive 30 to 40 percent of their revenue from products and services introduced within the most recent five years. [1] As the result the importance of reducing development project cycle time has risen dramatically. To accelerate product development firms in many industries have shifted from a sequential development paradigm to a concurrent paradigm. However implementing concurrent development activities in practice has often proven difficult. [12]

Reducing project cycle time leads the company to success

Nimble firms, those that can respond effectively to rapidly changing customer needs, will confirm a client's market-entry opportunity and lead the competition as we approach the twenty-first century [13]. Therefore in recent years the importance of reducing development project cycle time has risen dramatically. Effective new product development involves minimizing the resources (time, people, and raw material etc.) required to deliver an appropriate mix of product features, performance, quality, price and availability to customers. And the reduction of cycle times has been considered crucial to product success by researchers and viewed as a potential competitive advantage [12]. The impact of cycle time on product success is enormous. Its impact is considered larger than the other impacts, e.g. product development budget overruns and the labor lack.

Concurrent Engineering Shortens Product Development Time

Until international competition intensified, traditional new-product development was largely a serial process, using a waterfall model. When one design group finished its work, the work was thrown over the wall to the next group. Products were designed and systems developed in an assembly-line fashion [3]. To shorten the time it takes to finish a project and eliminate delays inherent in the waterfall model, many companies have overlapped the phases. Overlapping phases is known as a part of concurrent or parallel engineering. CE principles have been widely adopted to replace sequential, ”over-the-wall” processes and to shrink lead-times in product design. Concurrent engineering is a practice of concurrently designing the product and its downstream production to shorten product development time [4]. Concurrent development involves integrating and performing various engineering activities in the product development process in a parallel, rather than sequential process [11]. We can achieve the large reductions in cycle time reduction by applying concurrent development [12].

Concurrent development saves time due to 1) parallel processing of activities, 2) better and timelier identification and solution of problems, and 3) reduction of the hurdles between functions through which products must pass with a traditional stage-gate system. [5] An overlapping process lowers the imaginary ”wall products are thrown over” because product and process requirements and constraints are communicated earlier and more broadly throughout the development team.

Project Management with Implementing CE successfully

The effective management of development projects is also critical to project success. This is reflected in a recent survey of 498 developers which reported that over a third of the total time spent in product development was spent “managing/directing/appraising the entire process” and that this activity was three times larger than any other development activity. [6] One of the primary impacts of more concurrent development is an increase in the difficulty of managing projects. [10] This is partially due to the increased impacts of dynamic project features such as feedback, delays and nonlinear relationships caused by concurrent development. While we reduce the cycle time, we increase the project complexity simultaneously.

Therefore providing for increased management requirements for development projects is a major challenge of implementing concurrent development. Concurrent development need more management partially because of the increased quantity of interaction among any project features which are addressed by management such as setting development targets, providing resources, improving developer communication and coordination of simultaneous activities. Concurrent development can also increase management complexity by adding design requirements and increasing the intensity, frequency, direction and timing of information transfers with in and among development phases. These changes increase the dynamic impacts the feedback, delays and nonlinear relationships that link these features [7]. And they cause the generally poor understanding of project complexity and impacts of dynamic features of managers.

Although increased concurrence is generally assumed to decrease project manageability this assumption has not been adequately tested. The extent, nature and conditions of the causal relationships between concurrence and project manageability has not been adequately described and investigated. Not adequately addressing such new and larger management challenges can defeat efforts to accelerate development with concurrence. But knowing how to change project management to successfully implement concurrent development requires understanding how, when and to what extent concurrence impacts project manageability, not just that more management is required. An improved understanding of the relationship between dynamic concurrence and project manageability can lead to significant improvements in project performance.

PROBLEM DESCRIPTION

<u>Research Problem</u>*: Project managers do not understand the impacts of concurrence on project manageability adequately to design changes in management for reducing cycle time.*

As some research and practice literatures indicate, concurrence has an important impact on project management requirement. They suppose that concurrence and project manageability are inversely related, i.e. more concurrent projects are more difficult to manage [7]. Clark and Wheelwright describe increased cross-functional integration required by concurrent development. [12]

There are several difficulties, which help explain why this important concept has not been tested.

First, no adequate description of concurrence for understanding the link between concurrence and manageability has been developed. Related to this difficulty is the lack of metrics that relate concurrence to project manageability. Traditional project models, which describe concurrence such as the critical path method and PERT measure concurrence with the temporal, overlap of project activities [9]. But concurrence impacts manageability through the work performed in specific development processes and time is a measure of effects of that link, not a measure of the relationship itself. Ford operationalized process concurrence by using the internal process concurrence relationship and external process concurrence relationship and measures the amount of concurrence with the degree, which described a dynamic relationship among development tasks [7]. However these descriptors are not quantified or uniquely relate concurrence relationships to project manageability. Therefore an improved description and metric for development concurrence based on development work is needed.

The second cause of difficulty in testing the concurrence-manageability relationship is the lack of tools for describing and measuring project manageability. In the reality, what does the manageability mean and how can it be measured. Ford suggested a tool to measure manageability - process work queue acceleration, which has not been sufficient, validated yet and does not include the richness of features and characteristics which management capacity includes. [7]

The third challenge is that the nature of the causal relations between concurrence and manageability has not been made explicit by describing the agents and interactions that make manageability change with concurrence. Most studies linking concurrence and project performance suggest that causal relationships exist by identifying correlation between concurrence and performance variables. However these studies do not build explicit causal hypotheses which link concurrence relationships and project manageability.

More specifically, this study seeks answers to the question "How do the dynamic concurrence relationships impact development project manageability?" Several related questions will be investigated to improve our understanding of this issue:

- How can differences in concurrence relationships be described and quantified?
- How can development project manageability be described and measured?
- What casual relationships link dynamic concurrence and development project manageability?
- What agents and interactions describe the causal relations between concurrence and manageability?

RESEACH HYPOTHESIS

Measures of Concurrence

Degree of Concurrence (DC): Process Concurrence Relationship (PCR) captured the degree and character of the interdependence of the tasks aggregated. Ford defined Degree of Concurrence (DC) as the area between the 45° line, which bisects the PCR graph and the curve describing the phase internal concurrence. [7]

The paper gives the formula, which can theoretically be used to calculate DC:

$$DC = (\int_0^1 f(x)dx - 0.5) * 2 \qquad (1)$$

where

f(x) - Concurrence Relationship Function

In the model the following formula is used to substitute DC approximately:

$$DC' = (\sum_{i=1}^{20} f(x_i) * \Delta x - 0.5) * 2 \qquad (2)$$

where

$\{x_i\}$ - a sequence $0 = x_1, x_2, \ldots, x_{20} = 1$ and $x_k - x_{k-1} = \Delta x = 0.05$

Degree of Concurrence Relationship Curvature (DCRC): To explicate the other important character of the concurrence relationship curve, curvature of concurrence relationship curve. The paper uses curvature c(x)[1] to describe how curved the curve is [2] with owing to the 'shape' information it yields.

$$c(x) = \frac{d^2 f / dx^2}{(1 + (df / dx)^2)^{3/2}} \qquad (3)$$

where

f(x) is concurrence relationship curve

Curvature value at any point on the concurrence relationship curve can be easily calculated from Eq. (3).

To calculate how curved the whole curve is the paper expresses Degree of Concurrence Relationship Curvature (DCRC) as an accumulation of the value of point curvature. Given a sequence $0 = x_1, x_2, \ldots x_{20} = 1$ and $x_k - x_{k-1} = \Delta x = 0.05$, The paper uses the sum of the absolute value of curvature represent the DCRC approximately in the model.

$$DCRC = \sum_i |c(x_i)| \qquad (4)$$

Measures of Project Manageability

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1 $\rho = \frac{(1 + (dy / dx)^2)^{3/2}}{d^2 y / dx^2}$ is known as the radius of curvature at a point on a curve. Here the paper uses c = 1/ρ as the description of curvature.

Process Work Queue (PWQ) is the total amount of work waiting to be initially completed, checked, or iterated. In his model the process work queue is the work the project manager is trying to manage scope, resources and targets to complete satisfactorily and release. PWQ acceleration (PWQAccel) is defined as the second derivative of PWQ. Applying an analogy of return and its standard deviation to measure the uncertainty in the financial investment the paper uses the Standard Deviation of PWQAccel to describe the project manageability:

$$StD = \sqrt{Var(PWQAccel)} \tag{5}$$

And Manageability Index (MI) is definded as the inverse of the Standard Deviation:

$$MI\,(Manageabil\ ityIndex\,) = \frac{1}{StD} \tag{6}$$

Hypotheses

Two hypotheses were developed from the paper question, which tested the causal relationship between dynamic concurrence and project manageability under the two different conditions — Linear Concurrence Relationship and Nonlinear Concurrence Relationship.

Hypothesis 1: With linear concurrence relationship, increasing DC will reduce the project manageability.

The hypothesis stated above deal with the causal relationship between the dynamic concurrence and project manageability when PCR is linear. The concurrence relationship can be generally expressed as **Y=a+bX**. The paper operationalized the hypothesis that in the linear PCR condition more concurrence means that the project is more difficult to manage. Here the paper uses DC as a key measurement for project dynamic concurrence while supposing that there is no significant causal relationship between **a** (initial value), **b** (slope) and project manageability.

Hypothesis 2: With nonlinear concurrence relationship, DC and DCRC will affect the project manageability concurrently.

The hypothesis stated above deal with the causal relationship between the dynamic concurrence and project manageability when PCR is nonlinear. In order to summarize the different nonlinear curve identify four unique curve patterns in the concurrence relationship: Exponential Curve, Logarithm Curve, 'S' Shape Curve and Oscillatory Curve, which characterizes most kind of nonlinear curves in the concurrence relationship (Figure 1).

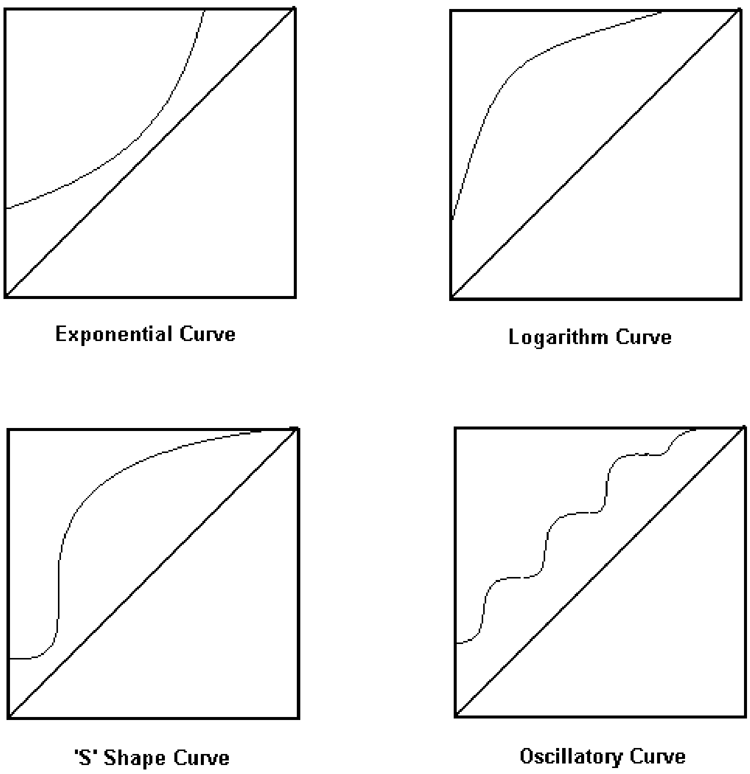

Figure 1: Four PCR Curve Patterns

The paper operationalized the hypothesis that in the nonlinear condition more concurrence doesn’t necessarily mean that the project is more difficult to manage as Ford’s experiment results showed. DCRC also is introduced as an additional key measurement for dynamic concurrence. The paper suppose that the combination of DC and DCRC will affect the project manageability inversely.

RESEARCH METHOD

SD Model based Data Collection Tool

In the experiment paper uses system dynamics model as a data collection tool, which is simplified from the project model given by Ford and Sterman [8]. To facilitate the study of concurrence and manageability the paper separated the process drivers of project performance from scope, resource and target drivers. It allows me to isolate process concurrence impacts by making simplifying assumptions concerning the impacts of scope changes, resources, and targets: project scope is assumed to remain constant, resources is infinite in quantity and quality and project targets are assumed not exist.

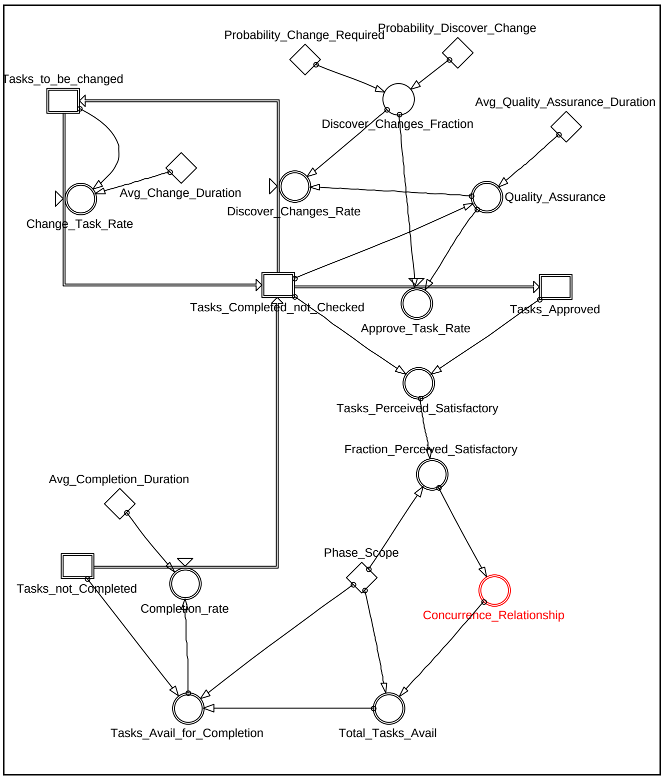

Figure 2: Development Process Model Stocks and Flows in a Single Phase

The System Dynamics model used here simulates the flow of development tasks through single-phase of a project. Figure 1 shows Stocks and Flows Diagram. The model uses three features to describe the development processes in a single phase: circular iteration, multiple development activities and available work constraints. Circular iteration is described with the stock and flow structure of the model (Figure 2). Development tasks flow into and through four states: Tasks not Completed, tasks Completed but not Checked, Tasks to be Change and Tasks Approved. Tasks enter the development phase as developers Initially Complete tasks. They accumulate in a stock of tasks Completed but not Checked. If no tasks are defective or those defects are not found when checked during Quality Assurance the tasks leave the Completed not Checked stock through the Approved Tasks flow and accumulate in the stock of Task which have been checked and released. This represents delivering tasks to downstream phases or to customers. Defective tasks are discovered through the Quality Assurance activity. Tasks found to be defective move through the Completed not Checked stock through the Find Defective Tasks flow and accumulate in the stock of Tasks to be Iterated. These tasks are reworked through the Iteration activity and returned to the Completed not Checked stock for another inspection by Quality Assurance. Defects can be generated during both initial completion and iteration. Therefore tasks being reworked to correct an error or improve quality may become defective during iteration.

Base Case Model

The paper uses a linear PCR case as Base Case to demonstrate the model behavior and the data collection procedure. Model simulation setup parameters:

Start Time = 0

Stop Time = 30

dt = 0.1

Integration Method = Euler (fixed step)

The Process Concurrence Relationship is shown in Figure 3 as a graph function:

$f(x) = 0.1 + x$ (when $0 \le x \le 0.9$); $f(x) = 1$ (when $0.9 < x \le 1$)

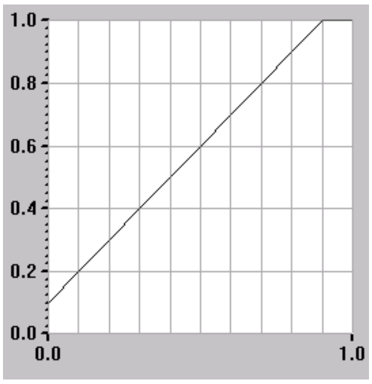

Figure 3: Table Function – Base Case's Concurrence Relationship

Running the simulations of Base Case model we got the model behaviors with a single phase. Figure 4 shows the behavior of four development tasks stocks: Tasks not Completed, Tasks to be Changed, Task Approved and Tasks Completed not Checked.

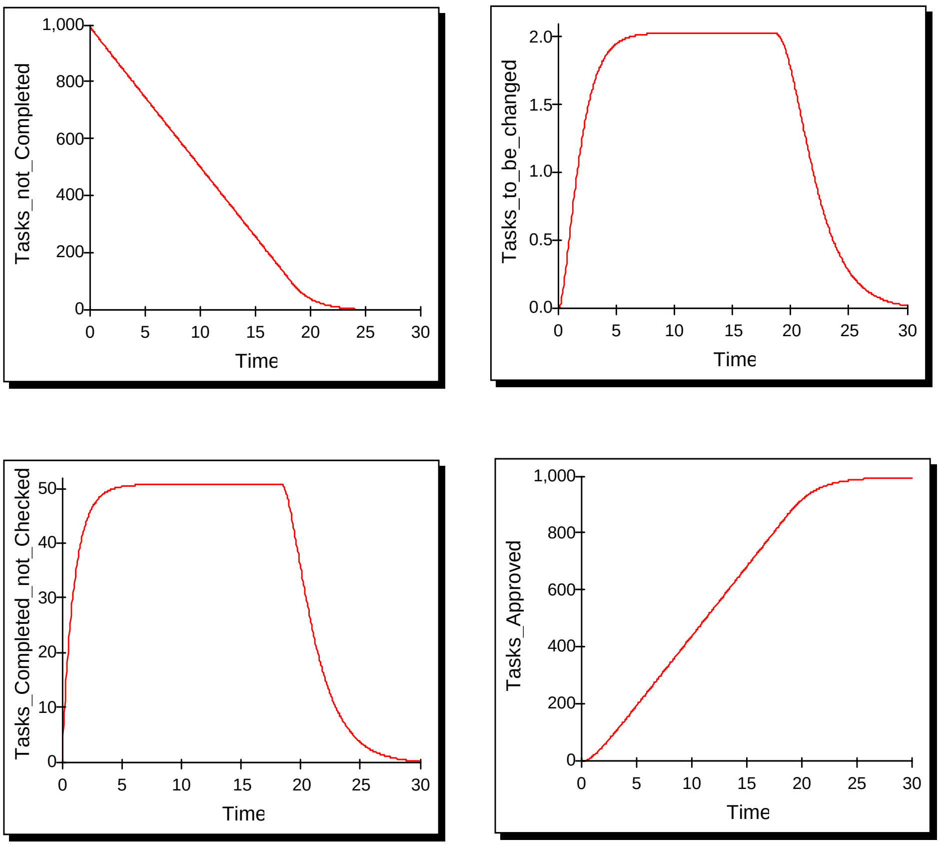

Figure 4: Base Case Model Behavior

Model Indicators are shown in the Table 1

Degree of Concurrence	a	b	Manageability Index
0.145	0.1	1	0.031

Table 1: Indicators in the Base Case Model

Data Collection Method

The system dynamics model represents the causal interactions that link process concurrence and project manageability in development projects through modeling and measuring dynamic concurrence relationship and project manageability. The paper uses the model as a test bed for experiments to improve our understanding of how concurrence impacts manageability, the impacts of different process concurrence relationships on project manageability.

SD model was developed, which are based experiments with two different conditions – Linear and Nonlinear PCR. In each condition the paper classifies four sorts of curves (as Table 2 shown). The table also shows the different equations, which represent the different sorts of curves in each other.

Linear PCR		Nonlinear PCR	
Linear 1	$Y_1 = \mathbf{a} + \mathbf{b}\, X$	Exponential Curve	$Y_1 = \mathbf{a} + \mathbf{b}\, X^2$
Linear 2	$Y_2 = \mathbf{a} + \mathbf{b}\, X$	Logarithm Curve	$Y_2 = \mathbf{a} + \mathbf{b}\ \mathbf{ln}(X)$
Linear 3	$Y_3 = \mathbf{a} + \mathbf{b}\, X$	'S' Shape Curve	$Y_3 = \mathbf{a} + (1\text{-}\mathbf{a})*((\exp(\mathbf{b}*(X-c)))/(1+\exp(\mathbf{b}*(X-c))))$
Linear 4	$Y_4 = \mathbf{a} + \mathbf{b}\, X$	Oscillatory	$Y_4 = \mathbf{a} + \mathbf{b}\ \sin(\mathbf{b}*X)$

Table 2: Two experiment Condition – Linear and Nonlinear

Using the SD model to generate the synthetic data in the two different conditions the paper applies the correlation-regression analysis to test Hypothesis 1 and Hypothesis 2, which will help us to reveal the causal relationship between concurrence and manageability. The paper first generates a correlation coefficient, a measure designed to ascertain the strength of a relationship between two variables. If the correlation coefficient thus generated is large enough to demonstrate a meaningful relationship between the variables, a *Linear Regression Equation* may be generated. This is a mathematical equation designed to predict what a subject's score would be along the dependent variable if we had knowledge of the subject's score on the independent variable. Thus we go a step beyond measuring the strength of a relationship into the realm of making predictions. The larger the correlation coefficient, the more accurate our predictions will be.

DATA ANALYSIS AND RESULTS

Linear Experiment

To check whether there is any significant relationship between the Degree of Concurrence and Manageability Index, the paper did a correlation-regression analysis Statistical test. The large inverse coefficients (= -.832) indicated that there is a significant inverse relationship ($p<0.005$) between the Degree of Concurrence and Manageability Index. This result supports Hypothesis 1 — with linear concurrence relationship, increasing DC will reduce the project manageability.

Nonlinear Experiment

The paper did a stepwise multiple regression analysis to check whether there is any significant relationship between the Manageability Index and the combination of DC and DCRC. DC with a higher negative coefficient (-.598) is much better for predicting MI than DCRC (-.323). The data also show that DC is statistically significant ($p<0.005$) while DCRC in step 2 is not statistically significant, p= .27 and excluded from the entry of the regression equation. This result fails to support Hypothesis 2 — with nonlinear concurrence relationship, DC and DCRC will affect the project manageability concurrently. There is no correlation between DCRC and MI. The result contrasts with the intuitive belief that increasing DCRC will reduce the project manageability. It suggests that other necessary requirements for improving the measurement of curvature were not provided in the experiment.

Although the main hypothesis was not statistically supported, the results indicate that at least DC affects the project manageability (with coefficient = .598), which proofs that there is a causal relationship between dynamic concurrence and project manageability.

More, DC coefficient (-.598) is not large enough (Std error =. 508) to predict the dependent variable (MI) alone, which also confirms the conclusion of Ford's experiment (Ford 1996) that the Degree of Concurrence alone cannot predict the impacts of development processes on project manageability.

CONCLUSIONS

Major Findings and Discussion

As started earlier, the research question for this study is to investigate " *how do the dynamic concurrence relationships impact development project manageability?* " Developed from this research question were two hypotheses, which tested the causal relationship between dynamic concurrence and project manageability under the two different conditions — Linear Concurrence Relationship and Nonlinear Concurrence Relationship.

First, the study confirms that there is an inverse causal relationship between the dynamic concurrence and project manageability no matter whether concurrence relationship is linear or nonlinear.

Second, the results of the first experiment indicate a significant negative relationship between the degree of concurrence and project manageability with linear concurrence relationship. This supports the hypothesis that with linear concurrence relationship, increasing DC will reduce the project manageability.

Third, when the concurrence relationship was changed from linear in the first experiment to nonlinear in the second experiment the relationship between the dynamic concurrence and project manageability became quite unexpected. The results didn't support the hypothesis that with nonlinear concurrence relationship, DC and DCRC will affect the project manageability concurrently. The experiment indicates there is no correlation between DCRC and MI. The result contrasts with the intuitive belief that increasing DCRC will reduce the project manageability. It suggests that other necessary requirements for improving the measurement of curvature were not provided in the experiment. While the nonlinear experiment results confirm the conclusion of Ford's experiment [7] that the Degree of Concurrence alone cannot predict the impacts of development processes on project manageability.

Future Study

The findings and limitations of this work point to potentially valuable extensions. They include the investigation of:

- Improvement of description for dynamic concurrence
- Improvement of description for project manageability
- A better data collection tool e.g. multiple-phase process model can be applied.

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