ESTIMATING OPTIMAL PROJECT DURATION AND COST FOR SOFTWARE DEVELOPMENT PROJECTS UNDER CONDITIONS OF TEAM SIZE DEPENDENT PRODUCTIVITY: SYSTEM DYNAMICS PERSPECTIVE

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ABSTRACT

Findings from our System Dynamics model provide useful pointers to software development project managers. Communication effects among project members, resultant productivity losses and incidental overload are incorporated into this model. Simulating a hypothetical project, we demonstrate estimating project duration and cost under different scenarios as well as estimating optimal team size and optimal project duration.

Dividing a project into smaller modules may be beneficial to prevent productivity losses due to communication overload. Likewise, starting a project with larger than required team size may be beneficial to prevent delays rather than to add staff midway to avoid training overload.

1.0 INTRODUCTION

Traditional methods of project management and analysis, while being very informative, did not focus much on the relationships between the parts of a system or to view the project from a holistic perspective. Hence, traditional methods are often found to be deficient to deal with the behavioral complexity involved in project management situations, thereby fail to provide useful guidance to project managers in those areas of project management. Basically, it is a case of taking a static view of the project versus being capable of capturing a dynamic view of project in action. Reviews of project progress often result in additions to project work causing a rippling effect of delays and cost overruns. Since traditional approaches to project management have proven deficient to cope with the increasing complexity of project management, new and more sophisticated techniques are needed to improve and manage project performance. Obviously, we need to employ models that have the power to capture and reflect interaction between different parts of a system as well as provide a holistic perspective. System dynamics models provide such capture of interaction between system variables and their behavior over time by facilitating the viewing of the project as a complex system.

Sterman (1992, pp 2) stated, "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." It then follows that, there is need for greater research in the area of project management for deeper understanding of the dynamic complexity involved.

Dynamic complexity, delays and feedback loop effects present in project settings have made Project management a topic of interest for system dynamics researchers. Considerable research has been done studying project management using a system dynamics approach by Cooper (1980), Richardson and Pugh (1981), Morecroft and Abdel-Hamid (1983), Abdel-Hamid (1984), Ford and Sterman (1997), Lyneis et al., (2001), and by Park and Pena-More (2003). Alexandre Rodrigues and Terry Williams, of the University of Strathclyde, Glasgow, Scotland, have developed a project management integrated model (PMIM, 1996). However, certain features of software projects that are not explicitly addressed in prior research provide motivation for current work which is part of a series of studies Janamanchi and Burns (2005), Burns and Janamanchi (2006) and Janamanchi and Burns (2011). In prior studies of this series (2005 and 2006), change management and earned value management concepts have been focused upon. More recently, in 2011, the effect of team size on productivity and possible insights to tackle and leverage these productivity effects in managing projects cost effectively has been taken up. Current study is an extension of this new focus of studying the effect of productivity on project dynamics.

The project type considered here is of the software development type that involves a lot of communication and interaction overhead. This communication and interaction overload is in contrast to conventional construction projects where the communication overhead is minimal and there are many trained human resources readily available. The effects of a time-varying project team size in which new members must be provided orientation and training before they can be added is addressed by the models presented here. As team size increases, productivity declines because of the communication overhead. The resultant lowering of productivity in the aggregate is incorporated into existing project dynamics model structures. Therefore, within the existing structure, these additional considerations are included—training and interaction (communication) overhead, additions to project work and the effects of increasing team size.

Traditional tools and techniques have proven inadequate to provide quick and reliable information to the project manager. Therefore, to effectively and efficiently manage the project, project managers must use a combination of the traditional models, mental models and System Dynamics models. "The application of System Dynamics to Project Management covers a wide range of uses, in particular creating team learning and training environments, providing a tool for advanced planning and control of on-going projects, and post mortem analysis to support legal dispute resolution" (Rodrigues and Williams, 1996).

The remainder of this paper is organized as follows. Section 2 discusses the choice of software and explains the general outline of the hypothetical project being modeled, with the details of the Vensim model developed using Vensim Professional version (Vensim 2011). Additionally, section 2 also discusses the team size effect on productivity and the manner of adopting the same in the current model. Further it provides a discussion of certain important decisions that a project manager need to take in the context of each project. The results from the simulation of base case and several alternate scenarios under varying model settings are presented with comments in section 3, followed by discussion of inferences that may be drawn from these results. Finally section 4 lists the contributions, limitations of our model and possible future improvements.

2.0 MODEL DESCRIPTION

We choose to develop our model using Vensim Professional application software (Ventana 2011). Since basics of a typical project management model are well known to the DSI community, we go straight to the discussion of the project being modeled.

2.1 The Project: The project stereotype we are dealing with here is a seemingly simple software technology project. However, the seemingly simple project needs to be planned and executed with caution in the view of the often-quoted Brook's law, "adding resources to a late project makes it even later." Brook's statement was made with specific reference to software projects (Sterman, 1992). If the project was to be characterized into the two categories identified by Boehm (1981) and referred by Morecroft and Abdel-Hamid (1983), then it would be a hi-bred of 'organic mode' and 'embedded mode' with a greater lean towards the embedded mode.

Simply explained, our model consists of two main segments, 'project work,' and 'project staff.' Workload requirements affect the staff assignments to the project, and the project team size influences the workflow rate, subject to the productivity factor. Schedule pressure factor affects the rejection rate and staff turnover normal. Staff turnover normal affects the staff turnover rate, which in turn affects the staff requirements and hiring rate. In its present form, the model consists of three basic components, a project-staff-and-wages component that includes a staff pool from which project staff are extracted and returned, a work sector, and the third being a project cost accumulation sector. In the work sector, there are four stocks: project-work-to-be-done, project-work-in-progress, work-completed and rework-identified.

2.2 Work Sector and Base Case Scenario

In a basecase scenario, the project starts at time 0 (months) with an 'initial-contracted-load' (expressed in person*month). Project staffing requirement arrived at by dividing the initial-project-load (person*month) by the 'scheduled-completion-time.' (denoted in months). The initial-contracted-load is, but logically, the starting value for the stock 'project-work-to-be-done.' Work performed, moves from the stock project-work-to-be-done to the stock 'project-work-in-progress.' However, the work flow is determined by the productivity factor that is derived from a table look-up based on the number of staff currently on the project; in other words, productivity is a function of project team size. The project-work-in-progress is routinely inspected. Inspection process is assumed to be built into the workflow and performed by the staff performing the project work; as such explicit staff assignment is not made for inspection process. Work failing to meet the required inspection standards moves to 'rework-identified' and the work that passes the inspection moves to 'project-work-completed.' Rework-identified gets priority over project-work-to-be-done because, typical technology projects build up in cumulative fashion.

2.3 Staff-and-wages sector: As stated before, staffing requirement is arrived at by dividing the initial-project-load by the 'scheduled-completion-time.' An appropriate fraction of project staff is assigned to attend rework, and the remaining staff tackles the project-work-to-be-done. As the project advances, at each time interval (which is "half a month" unit of time being one month), the requirements of project staff are assessed, and if additional staff is required based on scheduled completion, such additions are allowed. (Conversely, towards the end when there is surplus of staff on project they are moved back to the available pool). It is assumed that this particular enterprise has some available staff awaiting assignment to different projects. As the project advances, the available time declines, this causes an increase in 'schedule-pressure'. An increase in schedule-pressure increases rejection-rate and staff-turnover-rate. These changes have negative impacts on the project completion time.

We included a productivity multiplier in the model. Productivity multiplier declines as the team size increases. In a typical technology project, there is considerable communication and interaction overhead. The productivity multiplier factor is modeled based on data provided by Fried (1995). Fried provides productive time estimates for worker groups ranging from 10 to 100. However, based on Fried's comments, we have created productivity factor for smaller groups; "Therefore, it may be estimated that 55 percent of each employee's time can be considered productive in a group of up to 10 employees" (Fried, 1995, p.130).

Finally, the project dynamics model includes necessary structure for accumulating the project costs. We consider primarily project staff wages and dependent direct overheads and general administrative overheads.

2.4 Managerial decisions to be taken for each project: With the objective of completing a project on time and within budget each project manager has to determine,

a. the initial starting project staff and
b. the stage of project where surplus staff may be withdrawn safely without any side effects.

2.4.5 Alternate Scenarios

The major differences, between the base case and each of the alternate cases, are the staffing pattern and stage of project progress where excess staff is returned to staff pool. These aspects are deliberately varied to facilitate developing possible effects of inherent dynamics on the objective function and thereby to obtain useful insights for managerial decision making. Table 1 below summarizes the various scenarios simulated in this study

Scenario Name	Description
Basecase	250 man-months' work – with a schedule completion time of 25 months is started with 15 project staff and policy of not transferring staff until 75% of project is completed.
Basecase18	Same as above but initial project staff is 18 instead of 15
Basecase18Av	Same as above with the difference that staff transferred after 95% project completion instead of 75% completion
OptimizeBasecase	Vensim's built-in optimizer used to optimize parameters for above setting
Basecase10Months30	250 man-months' work – with a schedule completion time of

	10 months is started with 30 project staff and policy of not transferring staff until 75% of project is completed.
Basecase10Months40	Same as above but initial project staff is 40 instead of 30
Basecase10Months40Av	Same as above with the difference that staff transferred after 95% project completion instead of 75% completion
OptimizeBasecase10Months40Av	Vensim's built-in optimizer used to optimize parameters for above setting
Basecase5MonthsNoFWW50	250 man-months' work – with a schedule completion time of 5 months is started with 50 project staff and policy of not transferring staff until 75% of project is completed AND NO Flexible work week.
Basecase5MonthsNoFWW75	Same as above but initial project staff is 75 instead of 50
Basecase5MonthswithFWW75	Same as above with the difference that flexible workweek (up to 50% longer) is allowed
OptimizeBasecase5MonthsWithFWW	Vensim's built-in optimizer used to optimize parameters for above setting
GrandOptimize	Vensim's built-in optimizer used to find optimal parameters of scheduled completion, initial project staff, and staff transfer point

Table 1: Scenarios simulated in the model

2.5 Special Features in the model

A schedule performance index is computed as a ratio of Earned Value/Total Planned Value. Based on the performance index ranging from 0 to 1, a table lookup returns a multiplier ranging from 1.5 to 1 to be used for multiplying the typical work week of 40 hours. This results in pressing staff into overtime work during the phases when the gap is higher and relaxing overtime as the gap reduces. However, in this model overtime wages are paid at the regular rate of wages rather than at one and half times the regular wages. As may be noted, in all scenarios except for two denoted with NoFWW (for no flexible work week) in all other cases, work week is allowed to expand per need determined using the schedule performance index.

In the work sector (component) of the model, there is explicit provision for "Rework identified" rather than just returning this work to "Project work to be done." This allows for this work to be handled differently from "project work to be done" so that this work can be expedited, etc. At each iteration interval, project staff requirements are adjusted to meet the scheduled completion time. This adjustment is made by dividing the work yet to be done by the available time without considering the productivity factor, as a normal project manager would do based on his mental models.

All new staff joining the project past 1st month need training like the orientation to the current stage of the project with an appreciation of work done up to date, to be effective and the training time is one month considering the size of this project. Typically, in the initial stages at time points before 1st month no additional training is required since the initial project team is selected on the basis of their suitability to execute the project as well as the fact that the initial team defines the outline and manner of project execution. However, if new staff is to join six months into the project, they need about 2 months training before they are effective. Typically, as the projects get more and more complex as they progress, new members needs longer training.

3.0 SIMULATION RUN RESULTS AND DISCUSSION

The Stock and Flow Diagram needs the units, equations, and starting values for the stocks and rates to make simulation runs. We have already identified some of the required values in our description of the project under section 2. Given below is a complete list of all major assumptions and data values used in the model.

Assumptions and Data Values

- Work to be done: 250 man-months (person*month)
- Initial staff available: 50 (persons) for any project setting.
- Scheduled completion time: varied (extended monthly once reached)
- Initial project staff assigned: varied per scenario. These staff are in addition to the staff available pool
- Interaction effect is provided by way of table look up (Fried 1995)
- Staff requirements are adjusted on 1/4th month basis.(time step=0.25 month)
- New staff joining the project past month 1 need 1 month training-
- Rejection normal is initially set at 5%
- Acceptance normal is complement of rejection normal, hence 95% at start.
- Rework identified gets priority over project work to be done.
- All rework identified is assumed to be reworked within one month
- Project staff are allocated to rework first and the remaining are assigned to project work to be done.
- Entire (combined) project staff is taken as the basis for productivity table look up
- Available time is computed as 'schedule time-elapsed time,' subject to a minimum of 'one moth' at all times.
- Reduction in available time, increases schedule pressure ranging from 1 to 2 and this schedule pressure affects the rejection rate as well as staff turnover. So rejection rate can reach a high of 10% when schedule pressure is hits 2.
- Average wage per staff per month is $5,000.
- Available staff at all times needs to be maintained at 10% of the project staff.
- If-then-else logic is employed in many equations to prevent negative draining of stocks as well as to prevent recurring fractional computations

With the above assumptions and some constructs implicit for a Vensim model, the base case and alternative scenario runs are made and the results are discussed below. The so called base is a setting where a 250 man-month project is scheduled to be completed in 25 months. However, given that team size impacts the productivity the project in basecase is started with an initial project team of 15 instead of 10 as would have been the case if productivity were to be constant at 1.0 meaning, 100%. Initial policy is not to return project staff until 75% of the project work is done. Since this setting did not result in acceptable level of project performance, we experiment with increasing the initial staff to 18 in next setting, topping it with the policy of returning staff only upon completing 95% of project and so on. At this stage we try utilizing Powell's hill climbing algorithm's logic that's built into vensim software to assist in optimizing initial staff

setting and policy choice (of staff return) to minimize the objective function of project cost and project duration.
We then continue to experiment with scenarios where project is attempted to be completed in 10 days and 5 days with varying team size and staff return policies. We observe that with productivity losses arising from time varying team size, the project cost increase disproportionately very high for every effort at crashing the project completion time. Summarized results in terms of project end, cost involved under each scenario simulated are presented in table 2 below

Scenario Name	**availability after**	**Initial project staff**	**scheduled End**	**Actual End-Time**	**Total cost**
	%completed		**months**	**months**	
Basecase	**0.75**	**15**	**25**	**30.00**	**$ 5,770,000.00**
Basecase18	**0.75**	**18**	**25**	**28.50**	**$ 4,844,000.00**
Basecase18Av	***0.95***	**18**	**25**	**24.75**	**$ 4,751,000.00**
OptimizeBasecase	0.9	16.19	**25**	**27.75**	**$ 4,692,000.00**
Basecase10months30	**0.75**	**30**	**10**	**16.75**	**$ 7,135,000.00**
Basecase10Months40	**0.75**	**40**	**10**	**14.5**	**$ 5,592,000.00**
Basecase10months40Av	***0.95***	**40**	**10**	**15.75**	**$ 5,985,000.00**
OptimizeBasecase10Months40 Av	0.75	40	**10**	**14.5**	**$ 5,592,000.00**
Basecase5MonthsNoFWW50	**0.75**	**50**	**5**	**21**	**$10,590,000.00**
Basecase5MonthsNoFWW75	**0.75**	**75**	**5**	**29.25**	**$18,520,000.00**
Basecase5MonthswithFWW75	***0.95***	**75**	**5**	**22.25**	**$23,190,000.00**
OptimizeBasecase5Monthswith FWW	0.55	30	**5**	**21.25**	**$10,010,000.00**
GrandOptimize	0.9	16.26	**25**	**27.5**	**$ 4,683,000.00**

Table 2: Summarized Comparative results from various scenarios simulated.

Note 1: Parametric values in Italics (under **availability after** column) reflect policy changes
Note 2: Parametric values with underscores under column 2 and 3 were picked by the built-in optimization process in Vensim.

3.1 Inferences from the simulation results

Some straightforward inferences that may be made from the table 2 are as follows.

1. Due to the inherent dynamics involved in all projects, project executions will be delayed beyond the scheduled completion time, and project costs exceed the budgeted costs. Nominal rejection percentage set at 5% initially, which rises up to 10% as schedule pressure goes up, and rules regarding rework receiving priority cause additional costs and delays in project execution.

2. Team size productivity effects need to be factored in, while assessing the project staffing requirements as well as project cost budgets.

3. Without a planned holistic intervention to complete the projects within their scheduled times, all project executions will exceed their scheduled dates for the reasons of team size effect on productivity as well as the inherent rejection rate (error rate) in the project work.

4. Projects with marginally larger than required initial project staff result in lower overall costs.

5. Rule regarding transferring project staff during the progress of the project can greatly affect the costs and delays due to non-linear effect they may have on internal dynamics.

6. With productivity multiplier, crashing of projects results in disproportionately higher costs due to drop in productivity. This is more pronounced as you move away from the optimal schedule.

7. For most projects, depending upon the workload and productivity effect, optimal schedule and optimal staffing pattern can be obtained As may be observed from the grand optimization scenario, system recommends that for a project of 250 man-months with flexible work week, optimal scheduled completion time is 25-28 months and the optimal starting project team size is a little over 16 staff.

8. Smaller teams entail lower communication overhead and hence are more productive.

9. As was seen in the base case, typical increases in project costs with no interference could be as high as 100-200% (Typical cost accounting calculation would be: for 250 man-months wages 250*$5,000= $1,250,000+ direct overhead 20% thereof= $250,000 and GA overhead 25% of combined cost = $375,000 for a total of $1,875,000- Compare this with base case cost of $5,770,000)

10. Crashing the project from 25 months to 10 months was not excessively expensive; but further crashing it from 10 months to 5 months turned out to be counter-productive with disproportionately high cost and completion way-beyond the desired time.

11. Given that each project based on its work load appears to have an optimal schedule and optimal team size, opportunities for developing projects in independent modules must be explored wherever available. As can be seem projects with smaller teams tend to be more productive and cost effective.

12. Flexible work week, which is fairly beneficial at optimal and near optimal team sizes, becomes extremely counterproductive when applied in scenarios of large teams and ambitiously short schedule completion time.

4.0 CONTRIBUTIONS, LIMITATIONS AND FUTURE IMPROVEMENTS

4.1 Contributions: There are many useful contributions emerging from the model as follows.

1. The model incorporates the flexible workweek option in a project setting and also the effect of team size and interaction effect on the productivity of project team.

2. By varying the parameters (model constants) like, ‘INITIAL PROJECT LOAD,’ ‘starting team size,’ etc., several different project scenarios can be simulated.

3. The model provides decision support in assessing the effect of customer change requests of schedule completion time in an objective manner and to make suitable price quotes as well as provide help in resolving cost disputes arising out of change request.

4. The model can very easily be adapted to other types of projects by making suitable changes in the structure to reflect the peculiar/unique situations present under those projects.

4.2 Limitations of the model

Some explicit limitations of the model are,

1. All parameter values used in the model, like the workload, rejection rate, and acceptance rate are assumed for a typical/hypothetical technology project.

2. For simplicity sake, model assumes a steady rejection rate (affected only by the schedule pressure) but rejection and rework patterns may be different/ distinct in certain project settings.

3. Staff interaction effect and the productivity table look up that is modeled herein is assumed to take care of the effect of time lost in training the new members joining the team midway. No other explicit time loss is modeled.

4. Fractions in staff numbers are allowed on the assumption that the enterprise will be able to allocate the idle time to other useful productive tasks (other than the project).

4.3 Future Improvements

Many variations to the current model are possible to improve the usefulness and effectiveness of the model as a decision support tool. One could use real time data and provide decision support. Study further variations in project parameters to understand the dynamics involved to be able to manage projects better. As with other complex systems, gradually relaxing the simplifying assumptions permits study of more complex settings and scenarios.

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