On the Optimal Frequency and Timing of Control Points in a Project's Life Cycle

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ABSTRACT

The dynamic nature of projects and the fact that they are carried out in changing environments, justify the need for their periodic monitoring and control. Collection of information about the performance of projects at control points costs money. The corrective actions that may need to be taken to bring the project in line with the plan also costs money. On the other hand, penalties are usually imposed when due to "no monitoring" policies projects are delivered later than expected. Thence, this paper addresses two fundamental questions in this regard. First question concerns the optimal frequency of control during the life cycle of a project. The second question concerns the optimal timing of control points. Our solution methodology consists of a simulation-optimization model that optimizes the timing of control points using the attraction-repulsion mechanisms borrowed from the electromagnetism theory. A mathematical model is also used to optimally expedite the remaining part of the project when possible delays are to be compensated.

1. Introduction

A project can be considered to be any series of activities and tasks that:

- Have specific objectives to accomplish within certain specifications.
- Have defined start and end dates.
- Have funding limits (if applicable).
- Consume human and nonhuman resources (i.e., money, people, and equipment).
- Are multifunctional (i.e., cut across several functional lines).

Due to their relatively short durations and often prioritized control of resources, almost all projects require formal, detailed planning. Planning, in general, can best be described as the function of selecting the enterprise objectives and establishing the policies,

procedures, and programs necessary for achieving them. Planning in a project environment may be described as establishing a predetermined course of action. The project's requirements set the major milestones. Project planning must be *systematic* and *flexible* enough to handle unique activities, *disciplined* through reviews and controls, and capable of accepting *multifunctional* inputs.

Successful project managers realize that project planning is an iterative process and must be performed throughout the life of the project. One of the objectives of project planning is to completely define all work required so that it will be readily identifiable to each project participant. This is a necessity because projects are usually carried out in unstable environments, where many factors can affect their performances and delay their delivery times. Revision of activities, delay in delivery of materials, changes in technical specifications, unforeseen events are among factors that may force some changes to the plan.

After a project has begun to function in its assigned areas, supervisory measures assume prominence in the project life cycle. The term "control" refers to those

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steps taken to ensure that plans are properly executed. Control has been classically defined as verifying whether everything occurs in conformity with the plans adopted, the instructions issued, and the principles established. Project control consists of measuring actual execution, comparing it to the plan, analyzing the deviations, and initiating and implementing corrective action to bring the project back on course. The purpose of control then is to find deviations, correct them as early as possible, and prevent them in the future. The nature of project supervision and control thus requires a constant flow of information so that deviations from plans may be spotted and decisions and corrective actions may be taken on time.

There are two main issues involved in designing project control procedures. The first issue concerns the amount of control that should be exercised throughout the life cycle of the project, and the second issue is control timing. In 1988, it was suggested to design quarterly and weekly performance targets for projects, and also control their performance at major milestones [1]. It was also suggested that projects with life cycles less than 100000 hours should be controlled on a monthly basis, projects with life cycles more than 1500000 hours should be controlled on a weekly basis, and projects with life cycles in [100000..1500000] hours, presumably fitting in between. Control points should be linked to the actual project plans and to the occurrence of events as reflected in the plan, and not only to the calendar [2]. Flexibility, cost effectiveness, usefulness, timeliness, accuracy and precision, simplicity of operation, ease of maintenance, and full documentation are attributes of good control systems [2]. However, the question of how to determine the extent and frequency of control is not addressed. The frequency of reporting in project control depends on the length of the project, the stage of the project, the risks involved, and the organizational level of the report recipient [3].

A simulation study was used to compare the effectiveness of five control timing policies namely (i) control at equal intervals through the life cycle of the project, (ii) more control at the early stages of the project's life cycle, (iii) more control at the later stages of the project's life cycle, (iv) control at random points, and finally (v) no control [4]. Cost of bringing the project's performance with accordance to the plan, and also the ability to prevent time overruns are the two criteria that were used to compare the performance of the given policies. No significant differences among the policies in terms of cost required to recover from deviations from the plan was observed. A model based on the definition of an effort function for the quantitative determination of the timing of control points was proposed in [5]. It was assumed that control intensity is distributed according to a bell shaped curve around the point of maximum effort.

An analytical framework for determining the timing of project control was proposed in [6]. This framework is based on maximizing the total amount of information generated by the control points. This in turn is assumed to be based on the intensity of the activities carried out since the last control point. In this work however, the number of control is fixed.

In spite of recognizing the need to determine the number and the timing of project control, there are not many research papers addressing this issue.

In this paper we propose a hybrid simulation-optimization model that employs an evolutionary optimum seeking heuristic whose solution combination mechanism is based on concepts borrowed from the electromagnetism theory. The model initially seeks to find the optimum number of control points. It then tries to determine the optimum timing of control points.

The rest of the paper is organized as follows. In the next section the solution procedure is described. In section 3, we present our results. Conclusions are drawn in section 4.

2. Solution Methodology

The methodology proposed in this paper to find the optimum number and timing of control points consists of the following parts:

- A simulation model which simulates the execution of the project (number of control and other required parameters are given).
- An optimum seeking procedure based on the attraction-repulsion mechanisms of electromagnetism theory in order to optimize the timing of control points.
- A mathematical model that gives the optimum crashing plan of the project.

Execution of the project in time is conducted by the simulation model. To do so, it needs information about the project's activities and their durations, also their type, crashing cost and logical relationships. In addition it needs to know the number of controls. For each project, 0, 1, 2, 4, 6, 8, 10, 12, 15, 18, 21 control points are examined. As monitoring the project at control point costs money, the number of control has an upper bound beyond which the cost of control outweighs any benefit yielded by additional control. In simulation, activity durations are sampled from beta distribution whose parameters are also given. At each control point, in order to simulate the benefit yielded by the information gathered from monitoring the project, the variance of the beta distribution is reduced. The amount of reduction is based on the number and the type of activities that were monitored since the last control point, and also their relationships with the remaining activities. The cost function that is minimized during the optimum seeking procedure has the following characteristics:

$$Min \quad f = \sum_{i=1}^{3} f_i \tag{1}$$

Where

$$
\begin{array}{rcl}
f_1 & = & \upsilon_1(p_1, p_2) \\
f_2 & = & \upsilon_2(p_3, p_4) \\
f_3 & = & \upsilon_1(p_1, p_2)
\end{array}
$$

Element f_1 of (1) is the cost of control which in turn is a function of both the number (p_1) and the type (p_2) of the activities being monitored. It is reasonable to assume that not all the activities have equal monitoring cost. As such, we have randomly classified the project's activities into $k, k = 1,…,| A |$ groups, where A is the set of activities. Element f_2 of (1) is the cost of project crashing. This cost is incurred when it is necessary to expedite the project in order to compensate some possible delays. Crashing cost is in turn, a function of both the type of the activities being crashed (p_3) and also the number of time units each activity is being crashed (p_4). Element f_3 of (1) is the penalty for project late delivery. This cost is incurred when it is not possible to crash any more activities and as such the project's late delivery is inevitable. Penalties for late delivery are also a function of both the number (p_1) and the type (p_2) of the activities being performed later than planned. To find this cost, the execution of the remaining activities is simulated. The optimum seeking procedure coupled with the simulation model is based on the electromagnetism theory which is briefly described in the following section.

Electromagnetism Mechanism (EM) - EM is an evolutionary algorithm for global optimization. It converges rather quickly to optimum [7]. The algorithm works on a set of initial solutions, R, using the idea of directing the sample points towards local optimizers, utilizing an attraction-repulsion mechanism. Each sample point is considered as a charged particle whose charge is initially calculated. The value of function (1) at any point constitutes the amount of charge at that point. The magnitude of attraction or repulsion of the point over the sample population is also determined by the amount of the charge. The direction for each point to move is specified by evaluating a combination forces exerted on the point by other points. In our implementation of EM, only one point acts on other points. Experiments showed that this yields good results. In other words, for all pairs in R, say s_i and $s_j, i \neq j$, where $s_i = (cp_1, cp_2,…,cp_k)$, a force is exerted by point (solution) s_j on point (solution) s_i either attracting it to its neighborhood or being repulsed by it

$(cp_j, j = 1,…,k$ is the timing of control points, when the policy is to monitor the project k times during its life cycle). The force exerted on a point is inversely proportional to the distance between the points and directly proportional to the product of their charges. A charge, $q_{s_i s_j} \in [-1 \cdots 1]$ is defined for each point in R

$$q_{s_i s_j} = \frac{f(s_i) - f(s_j)}{f(s_w) - f(s_b)}$$

in which $f(s_i)$ is the cost of solution i, s_w and s_b are the worst and best solutions in R respectively. Attraction of s_i by s_j occurs when $f(s_i) > f(s_j)$. Repulsion of s_i by s_j occurs when $f(s_i) < f(s_j)$, and no action is taken when $f(s_i) = f(s_j)$. The force exerted by solution s_j on solution s_i is calculated as:

$$F_{s_i s_j} = (s_j - s_i) \cdot q_{s_i s_j}$$

According to the value of $F_{s_i s_j}$ new solutions are created in Euclidian space by moving from s_i to $s_i + F_{s_i s_j}$.

The outline of the algorithm is presented in Fig. 1. The following variables are used to describe this algorithm:

VAAP	:	vector of activities actual progress
ct	:	CPU time
tl	:	time limit
s(i, j)	:	jth element of ith solution in R
mcp(k)	:	monitoring cost at control point k
stp(k)	:	simulated time at control point k.
ptp(k)	:	planned time at control point k.
ccc	:	current crashing cost
R	:	set of solutions
T	:	project cycle time
T_r	:	project required delivery time
$f(i)$	:	solution i from R
$f(j)$	:	solution j from R
$f(w)$	:	the worst solution in R
$f(b)$	:	the best solution in R
s(i, j)	:	control point j of solution i
NOC	:	No. of control imposed on the project

```
load VAAP
last_control = 0,

f₁ = 0,  f₂ = 0

While (ct < tl)

 for i=1 : |R|

  for j = 1 : NOC

   k = s(i, j)

   simulate project on the light of VAAP for the interval

   [last_control .. k]

   last_control = k

   f₁ = f₁ + mcp(k)

   adjust Beta dist. params for the remaining activities

   update VAAP

   if (stp(k) > ptp(k) )

   if (project expedition is possible)

    crash project for (stp(k) – ptp(k)) units of time by

     Math-Model

     f₂ = f₂ + ccc

   end

   If (last_control < T_r )

   simulate project on the light of VAAP for the

   interval [last_control .. T_r ]

   calculate possible amount of f₃

   f = f₁ + f₂ + f₃

   q(i,v) = (f(i) – f(v)) / (f(w) – f(b))     v = 1,..,| R |   v ≠ i

   u(i, v) = (v – i).q(i, v)

   Move points accordingly.
end
```

Fig. 1. Outline of the solution Methodology

The mathematical model (Math-Model) used to optimally crash the project to compensate the delays simulated into activities progress, is adopted from [8].

3. Computational Experiments and Discussion of Results

In order to demonstrate the capability of our proposed methodology in analyzing the number and timing of control points, 1650 experiments were conducted (30 simulation runs per each network and in respect of each number of controls (30*5*11). The five randomly generated activity-on-arrow project networks having 18, 23, 25, 30 and 40 activities are required to be completed in 36, 54, 45, 110, and 94 units of time, respectively. These projects have different complexity indices ranging from 5 to 9. As *Elmaghraby* states: *"the measurement of the 'complexity' of activity networks seems to be needed in order to estimate the computing requirements and/or to validly compare alternative heuristic procedures"* [9].

For each project network, the following information is provided to the simulation model:

- Number and type of activities together with their logical relationships.
- Activities allowable crashing times and also their crashing costs.
- Activities duration distribution parameters (α, β).
- Number of controls and their initial timings.

Sensitivity Analysis – We can not compare our proposed methodologies performance in terms of how accurate and well it performs with existing algorithms as there are no similar grounds on which to compare the results. Neither the solution approaches nor the structure of the networks used in these studies are the same. As *Partovi, et al* observe:

"The effect of different control policies may depend on the details of the networks, factors such as density, network size, complexity indices, etc" [4]. All the previous studies are based on fixed number of controls, whereas in our approach we first find the optimum number of controls, and then try to determine their optimal timings.

However, in order to somehow demonstrate the validity of our proposed solution methodology we performed some sensitivity tests, some of which are discussed below.

By increasing the number of controls, monitoring cost, f_1, increases as expected (see fig. 2-top). However, the increase in f_1 is not linear. This is due to the fact that the cost of monitoring at each control point is a function of the number and also the type of activities that have been monitored since the last control point.

The number of controls has a similar incremental effect on the crashing costs. However the incremental rate is not linear as expected (see fig. 2-bottom). By increasing the number of control points, the rate of increase in f_2 slows down. This is because by approaching the end of the project life cycle, there are not many activities left that can be crashed.

Tables 1-5 display the simulation-optimization results with respect to the five randomly generated project networks under eleven different control policies. For different control policies, each table depicts the project's delivery time (T), percent late delivery when compared to the required delivery time (T_r) and elements of cost function, namely f_1, f_2, f_3 and finally the total cost, f.
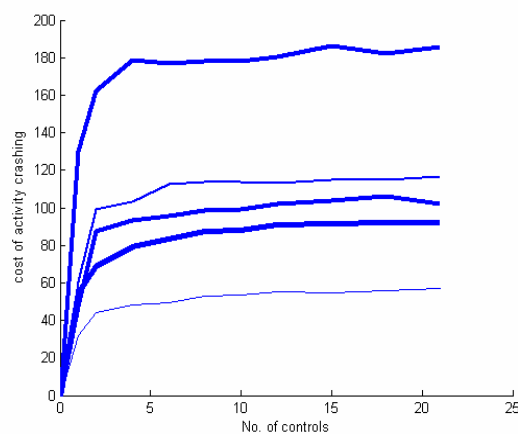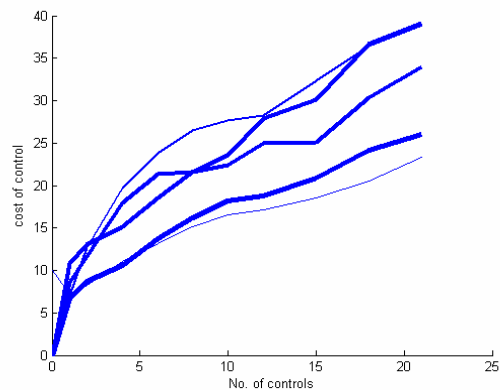
Figure 2. Costs of control (top) and activity crashing (bottom) vs No. of controls

Tab. 1. Mean costs and delivery time for project 1 under different control policies

No.	T	$<\%>T_r$	f_1	f_2	f_3	f
0	44.4	23.2	0	0	167.0	167.0
1	40.4	12.1	7.16	31.7	87.2	126.0
2	38.9	7.9	8.2	44.1	57.9	110.3
4	38.3	6.5	11.0	48.3	46.8	106.2
6	38.2	6.1	13.2	49.3	46.1	108.6
8	38.2	6.0	15.2	52.8	43.3	111.4
10	38.1	5.8	16.5	53.4	42.5	112.3
12	38.0	5.6	17.1	55.0	41.0	113.1
15	38.0	5.8	18.5	54.9	42.3	115.0
18	37.9	5.4	20.5	56.0	40.2	119.1
21	38.0	5.6	23.3	56.8	40.5	120.6

Project costs, f (see column 7) as well as project delivery times, T (see column 2) is affected by the number of controls. When there is no control points during the life cycle of the project, the cost of

penalties, f_3 (see column 6) have its highest value as expected (see fig. 4).

Tab. 2. Mean costs and delivery time for project 2 under different control policies

No.	T	T_r $<\%>$	f_1	f_2	f_3	f
0	138.6	26.0	0	0	572.0	572.0
1	129.8	18.0	8.6	129.9	396.4	534.9
2	127.4	15.9	11.6	162.3	348.9	522.7
4	126.3	14.8	18.0	178.7	326.2	522.9
6	126.3	14.8	21.3	177.0	325.3	523.6
8	126.2	14.7	21.6	177.9	323.2	522.7
10	126.1	14.7	23.6	178.2	323.0	524.8
12	125.9	14.3	27.9	180.3	318.8	527.0
15	125.7	14.3	30.1	186.3	314.1	530.5
18	125.9	14.4	36.7	182.4	318.9	538.0
21	125.6	14.2	39.1	185.9	314.6	539.5

Tab. 3. Mean costs and delivery time for project 3 under different control policies

No.	T	$<\%>T_r$	f_1	f_2	f_3	f
0	66.4	22.9	0	0	247.0	247.0
1	61.5	13.9	6.7	54.8	150.8	212.4
2	60.3	11.6	8.7	69.0	125.2	202.9
4	59.3	9.8	10.6	79.1	106.6	196.3
6	58.9	9.2	13.7	83.6	98.9	196.3
8	58.8	8.8	16.2	87.2	95.3	198.7
10	58.8	8.8	18.2	88.1	96.5	202.8
12	58.8	8.9	18.8	91.1	97.5	207.5
15	58.8	8.8	20.9	91.8	96.4	209.1
18	58.7	8.7	24.1	92.2	95.9	212.3
21	58.7	8.7	26.0	92.1	96.3	214.4

Tables 1-5, show that irrespective of the size, structure and complexity of the projects, as the number of controls increases from 0 to 5 control points during the life cycle of the projects, the cost function, f, decreases. The cost reduction initially has a higher rate. However, this gradually slows down. For example in project 1 (see column 7 of table 1) when the number of controls is increased from 0 to 2, f decreases by 34%. However when the number of controls is increased from 2 to 4 for example, f decreases by a small amount of 4%. This trend is observed in other projects as well (see Fig. 3).
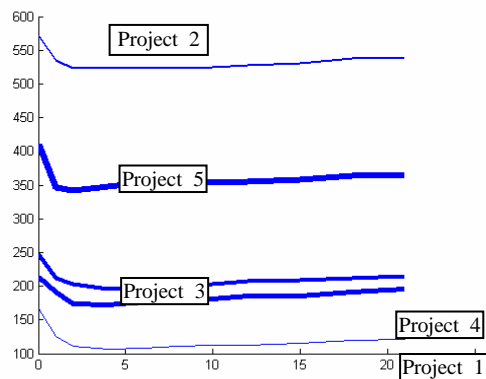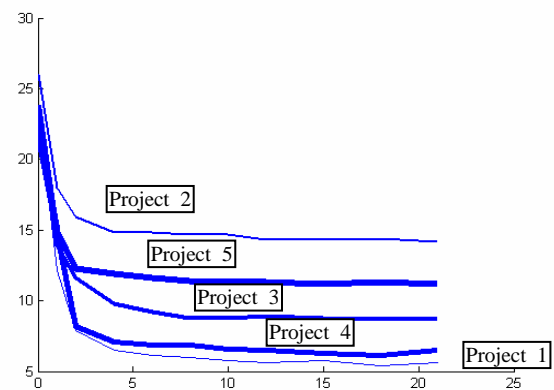
Fig. 3. Project costs versus number of controls

Tab. 4. Mean costs and delivery time for project 4 under different control policies

No.	T	$<\%>T_r$	f_1	f_2	f_3	f
0	55.7	23.8	0	0	214.0	214.0
1	51.6	14.7	10.8	47.9	132.2	190.8
2	48.7	8.2	13.0	87.5	73.9	174.5
4	48.2	7.1	15.1	93.1	64.1	172.3
6	48.1	6.9	18.5	95.5	61.9	176.0
8	48.1	6.9	21.6	98.7	62.1	182.5
10	47.9	6.6	22.4	99.1	59.6	181.2
12	47.9	6.5	25.0	102.0	58.7	185.7
15	47.8	6.3	25.1	103.9	57.1	186.0
18	47.8	6.1	30.4	106.0	55.4	191.7
21	47.8	6.5	34.0	102.3	59.1	195.5

Tab. 5. Mean costs and delivery time for project 5 under different control policies

No.	T	$<\%>T_r$	f_1	f_2	f_3	f
0	114.5	21.8	0	0	410.0	410.0
1	107.9	14.9	7.13	60.3	279.5	346.9
2	105.5	12.3	12.7	98.9	230.9	342.6
4	105.2	11.9	19.7	103.0	224.6	347.4
6	104.9	11.6	23.8	112.5	217.5	353.8
8	104.7	11.4	26.5	113.6	213.4	353.6
10	104.6	11.3	27.7	113.6	212.5	353.8
12	104.6	11.3	28.2	113.4	213.6	355.2
15	104.6	11.2	32.3	114.8	211.0	358.2
18	104.6	11.3	36.4	115.2	212.3	363.5
21	104.5	11.2	38.9	116.5	207.9	363.3

Control policies have a similar effect on the delivery time of projects. For example, when there is no control projects are 23.2, 26.0, 22.9, 23.8, and 21.8 percent late in respect of their required delivery times. However, beyond 5 controls not a significant improvement in delivery time can be observed (see Fig. 4).

Fig. 4. Project late delivery versus number of controls

The optimal timing of control points is determined as follows. The project life cycle is divided into n equal intervals. In this study, $n = 3$. The output of each simulation run is a random sample from solution space with regards to the timing of the control points. It is therefore necessary to map each solution into the given intervals, and hence make the decision regarding the optimum timing of control points. Table 6 shows the solutions mapping into the given 3 intervals.

Tab. 6. Mapping of simulation solutions into three time intervals

	First Interval		Second Interval		Third Interval	
	No.	%	No.	%	No.	%
Project 1	21	70.0	3	10.0	6	20.0
Project 2	23	76.7	3	10.0	4	23.2
Project 3	21	70.0	4	23.2	5	16.7
Project 4	22	73.3	6	20.0	2	6.7
Project 5	22	73.3	5	16.7	3	10.0

By reference to table 6, it is observed that more than 70% of control points timings fall in the first interval. This suggests that having more control at the beginning of the projects life cycle is beneficial both to project costs and also to the projects delivery time.

4. Conclusions

In this paper a methodology based on simulation-optimization approach was proposed to address the questions of number of controls and also the timings of control points in a project life cycle. When compared to other studies, the proposed methodology has the advantage of being able not only to determine the optimal timings of control points, but also the optimal number of controls. To show the applicability of the model, 5 randomly generated projects were analyzed. It was shown than the number of controls has an upper

bound beyond which no significant benefits can be gained by more control. It was also shown that in the context of this study, it is more beneficial to have the control points in early stages of the projects life cycles.

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