Development Projects Cost Dynamics

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Abstract

Cost and time overruns have been a common characteristic of development projects in many countries. This paper presents a theory of cost and time overruns based on project cost structure. The cost of a development project consists of *base cost* and *progress cost. Base cost* keeps a project ready for physical progress. *Progress* cost creates real physical progress in the project. This cost structure has an important inherent dynamic characteristic with implications for the efficiency and effectiveness of project management. An imbalance between annual budget and ongoing projects results in an increasing inefficiencies and ineffectiveness unrelated to the quality of management in individual projects. Under such conditions, the policy governing the starting rate of the new projects becomes very important. The theoretical framework presented in this paper can explain at least part of the causes of time and cost overruns in terms of imbalance between development projects and development budget. The paper also suggests some policy recommendations for starting new projects.

Key words: Project management, development projects, time overruns, cost overruns

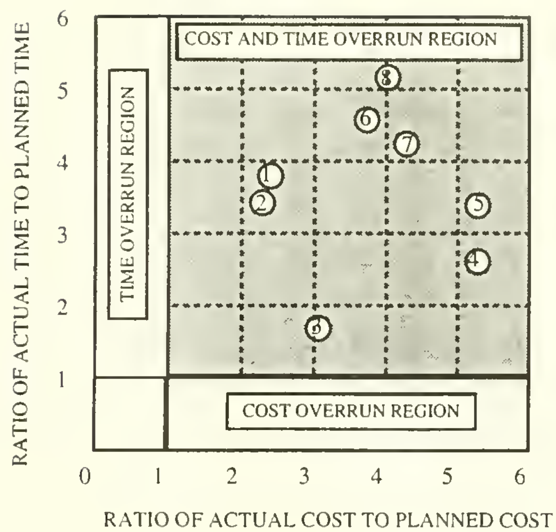
Introduction

In the evolution of economic growth theory, gross national investment has remained an important determinant of the growth of national production capacity [1,2,3,4,5]. However, the efficiency and effectiveness of the investment processes at a macro level has not been discussed in the literature. The efficiency and effectiveness of such a process is very important to the real contribution of investment to the growth of production capacity. Low efficiency in the investment process would result in less production capacity for each unit of gross investment made. Low effectiveness of the investment process results in a long construction period and increases the capital cost of investment projects. The efficiency and effectiveness of the investment process becomes very important to the growth of national production capacity when governmental investment in development projects constitutes a major part of national investment, as is the case in many developing countries.

Development projects are investment projects, undertaken by the governments of developing countries to construct infrastructure and production capacities to enhance and facilitate the development processes. Many developing countries have been experiencing cost and time overrun in their development projects[6]. For example, in Iran, completion costs and construction time of development projects are usually much larger than initially planned. Figure 1 shows the ratio of actual cost and construction time to planned values for development projects completed during 1989 and 1990. Point (1,1) indicates a position in which projects are completed according to the planned cost and time. All of the development projects completed during 1989 and 1990 in Iran are located in the high cost and long construction time region of the scatter, indicating low efficiency and effectiveness in project management.

Initial cost underestimation and inflation can contribute to the cost overrun. But not all of the cost overrun shown in Figure 1 can be attributed to these two factors. The whole sale price index in Iran rose from 100 in 1980, to 390 in 1989, and 530 in 1990 [7]. The average price index for a uniform capital expenditure from 1980 to 1990 was around a factor of 2. However, government projects usually enjoyed a fixed official exchange rate for their foreign procurements. For the domestic purchase of goods and services, development projects usually had access to goods at prices set officially by the government at a level lower than market prices. Therefore, inflation for the development project was lower than what the general price index shows, and certainly inflation alone can not explain the whole cost overrun. Because different prices that existed simultaneously in Iran, it is difficult to determine how much of the cost overrun was due to inflation.

The underestimation of cost, which might exist to some extent, is not a major factor because cost estimation is usually done based on some detailed feasibility studies by consultants. There are two reasons that the consultant should not want to underestimate the cost of the project. First, the consulting fees depend on the total cost of the project and second, the credibility of the consultant would be under question if the estimate turned out to be unrealistic.



1. Torogh dam
2. Montazeri steam power plant
3. Bakhtaran agricultural junior college
4. Minab water network
5. Tractor manufacturing plant
6. Poultry plant
7. Jiroft dam and power plant
8. 110 beds Shooshtar hospital

Figure 1: Cost and time overruns of projects completed in 1989 and 1990 in Iran.

Even if the cost ratio is reduced by a factor of 2 or 3 to take into account the effect of inflation and underestimation, cost overruns for development projects have still been considerable, as shown in Figure 1. High cost and long construction periods imply low efficiency and low effectiveness in the use of scarce investment resources. The higher cost of projects means that each dollar of government investment, through the development budget, generates lower production and less infrastructure capacity, both of which are required for the development of the country. A longer construction period results in higher capital costs for the huge capital resources that remain idle in the form of unfinished projects during the construction phase of projects.

Different factors can contribute to low efficiency and effectiveness of development investment. Most of project management literature focuses on the quality of project management. PERT and CPM, the dominant project management techniques, were first invented and implemented to plan, schedule, and coordinate different interrelated activities. They were intended to aid in completing projects effectively and efficiently within resource constraints, and required logical sequences of different activities. Development of more effective project cost controls [8], improvement of procurement management [9], better project organization [10], and effective contract management [11] have all been discussed and used to improve the quality of project management and increase the efficiency and effectiveness of investment project. Simulation techniques and cognitive mappings have been used to provide a better understanding and management of the overall dynamics of a single projects [12, 13] and the impact of client-contractor relationship on project delay and cost [14].

Although the quality of project management is very important, it is not the only factor causing long construction times and high completion costs. There are factors outside of project managers' control that contribute to such low performance. One such factor is a lack of balance between the development budget and financial resources required for development projects. In developing countries, the need for development is high and available resources are low. There is always pressure from citizens, regional officials and sectoral officials to start new development projects. These pressures lead to an imbalance between available resources and the number of projects consuming those resources.

In Iran, for example, according to the information obtained from the Plan and Budget Organization in 1991, the budget allocated to the construction of a hospital was about 30 percent of what was required to complete the ongoing projects on time with a four years construction period. In 1987, the allocated budget to water projects was about 22 percent of the budget required to complete those projects within an average construction time of five years [15].

This paper shows that this kind of imbalance between available and required resources has a profound impact on the performance of development projects. A project cost model is developed and presented in the next section. The model shows that even with perfect project management and without any inflation, the cost and completion time of development projects are affected by this imbalance. Any improvement in development project management requires a sound macro management of the balance between total number of projects and available resources in the development budget.

Model 1: The Basic Dynamics of Project Cost Structure

The annual cost of each project can be divided into two cost categories: *base cost* and *progress cost*. *Base cost* consists of all cost elements that should be paid to keep a project ready for physical progress. *Base cost* includes such items as the salary and overhead costs of the project manager and his staff, the cost of keeping contractors and consultants related to the project, and the cost of having construction machinery, equipment, and construction materials on site. *Progress cost* consists of those cost elements that, when paid in addition to the *base cost*, can create real physical progress. *Progress cost* includes such items as construction materials, construction labor, and the operating cost of construction equipment. Each project can be finished when a certain amount of progress cost has been spent to complete all the necessary activities in the project. *Base cost* has priority over progress cost, because base cost should be paid to create a condition in which progress cost can be effective.

Figure 2 shows a causal loop diagram of a basic dynamic cost structure model. The model consists of a positive or reinforcing loop [16, 17]. The dependency of one variable on another is shown by an arrow connecting the two variables with the following convention as is commonly used in System Dynamics [16, 17, 18, 19]:

$$x \xrightarrow{+} y \Rightarrow \frac{\partial y}{\partial x} \succ 0 \text{ or } \frac{\partial y}{\partial t} \succ 0 \text{ when } x \succ 0 \quad \text{and}$$

$$x \xrightarrow{-} y \Rightarrow \frac{\partial x}{\partial y} \prec 0 \text{ or } \frac{\partial y}{\partial t} \prec 0 \text{ when } x \succ 0$$

The variables of the basic model are:

$P =$ Number of ongoing development projects at different stage and measured in terms of *unit project*. *Unit project* is defined as a project that requires a certain amount of progress cost, called u, to be completed within normal construction time.

$S =$ Starting rate of new projects in each year measured in *unit projects per year* that increases the number of ongoing development projects.

$C =$ Completion rate of development projects in each year measured in *unit projects per year* that decreases the number of ongoing development projects.

$BB =$ Required annual base budget to pay base cost of development projects measured in *\$/year*.

$PB =$ Progress budget available to pay for progress cost in *\$/year*.

$D =$ Total development budget in *\$/year*.

$u =$ Progress cost required to complete a unit project in at a normal construction time *\$/project*.

$b =$ Annual base cost of a unit project in *\$/project/year*.

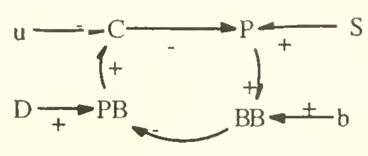


Figure 2: A causal loop diagram of basic dynamic cost structure model.

The equations for the model presented in Figure 2 are the following:

$$P = \frac{dP(t)}{dt} = S(t) - C(t) \qquad (1)$$

$$c(t) = \frac{PB(t)}{u} \qquad (2)$$

$$PB(t) = D(t) - BB(t) \qquad (3)$$

$$BB(t) = b \cdot P(t) \qquad (4)$$

Equations 1 to 4 lead to the following first order differential equation:

$$\dot{P} = \frac{b}{u} P(t) + S(t) - \frac{D(t)}{u} \qquad (5)$$

The general solution to Equation 5 is [20]:

$$P(t) = P(0) * e^{\frac{b}{u}t} + \int_0^t e^{\frac{b}{u}(t-\tau)} (S(t) - \frac{D(t)}{u}) \cdot d\tau \qquad (6)$$

In a simple case when the Starting Rate, *S*, and Development Budget, *D*, are constants, then the general solution is reduced to:

$$P(t) = \frac{P(0) \cdot b + u \cdot S - D}{b} \cdot e^{\frac{b}{u}t} + \frac{D - uS}{b} \qquad (7)$$

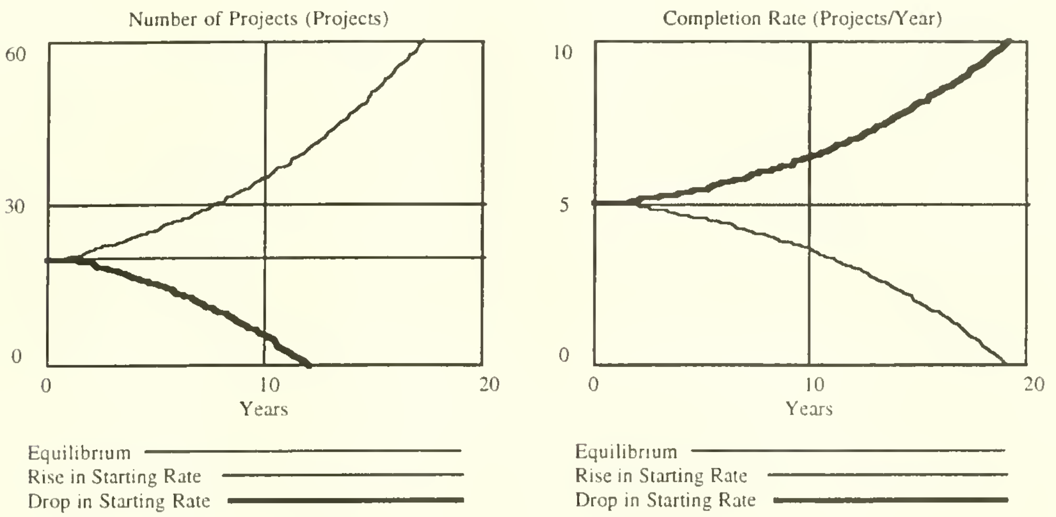
From equations 2, 3, 4, and 7, the completion rate, *C*, becomes:

$$C(t) = S - \frac{P(0) \cdot b + u \cdot S - D}{u} \cdot e^{\frac{b}{u}t} \qquad (8)$$

As Equation 7 shows, the number of projects has an unstable equilibrium value of $\frac{D - uS}{b}$ if the Starting Rate is $S = \frac{D - P(0) \cdot b}{u}$. Under this unstable equilibrium, the Completion Rate *C* becomes equal to the Starting Rate *S* and the number of project is such that the Base Budget *BB=P.b* and Progress Budget $PB = C \cdot u = S \cdot u$ add up to total Development Budget *D*.

If *S* becomes larger than its equilibrium value such the coefficient of $e^{\frac{b}{u}t}$ in Equation 7 becomes positive, $\frac{P(0) \cdot b + u \cdot S - D}{b} \succ 0$, then Number of Projects *P* increases to infinity and the Completion Rate *C* decreases to 0 and then, mathematically, to negative values. This characteristic of the solution indicates that the completion cost of projects could go to infinity and the efficiency of investment goes to zero. Under such conditions, capital investment would not lead to any increase in production capacity. If *S* becomes smaller than its equilibrium value such that the coefficient of $e^{\frac{b}{u}t}$ in Equation 7 becomes negative, then Number of Projects *P* declines exponentially and the Completion Rate increases to infinity. This unrealistic behavior, as will be discussed and corrected later, is the result of a simplistic assumption of constant progress cost for a unit project.

Figures 3a and 3b show some numerical results from the behavior of the model when starting rate is increased or decreased by a step function from equilibrium value of 5 by one unit at year 1. The parameter values for the behavior shown in Figure 3 are: *u=1, P(0)=20, b=.1, D=7, S=5 at equilibrium.*



3a- Behavior of number of projects. 3b- Behavior of completion rate.

Figure 3: Behavior of the basic model when the starting rate deviates form its equilibrium value by a step function.

As shown in Figures 3a and 3b, when starting rate becomes more than its equilibrium value, the number of projects rises and the required base budget becomes larger. When the base budget increases, less budget remains for the progress budget. Lower progress budget will decrease the completion rate which in turn causes the number of project to go still higher and completion rate to drop further.

If *S* becomes smaller than its equilibrium value, then the number of projects decreases and lowers the necessary base budget. More budget becomes available for the progress cost. Higher progress cost increases the completion rate and decreases the number of projects further leading to a still higher progress budget.

The basic model and its behavior discussed above show the inherent dynamic characteristic of the cost structure of development projects. However, in the real world neither the number of projects nor the completion rate goes to zero or infinity. To make the model more realistic, both the completion rate and the starting rate equations should be modified. In the equation for the completion rate, the progress cost to complete a unit project is assumed to be constant as u. When u remains constant, as the annual progress budget per unit of project rises, the completion time shortens and could approach zero while the progress cost of a unit project does not change. This assumption will be relaxed in the next section in order to modify the equation for the completion rate.

Model 2: Variable Progress Cost for Unit Project

In reality, when the completion time shortens to values less than a normal completion time, then coordination of different activities and also overtime and shift works become more costly and the progress cost of each unit projects should rise. At the extreme, to get the completion time close to zero, the unit cost should approach infinity. In order to capture this characteristic of the progress cost, the basic model is modified to create Model 2 as sketched in Figure 4. In the new model, two negative loops are added that will control the exponential decay behavior. The new variables and connections relative to Figure 2 are shown in bold.

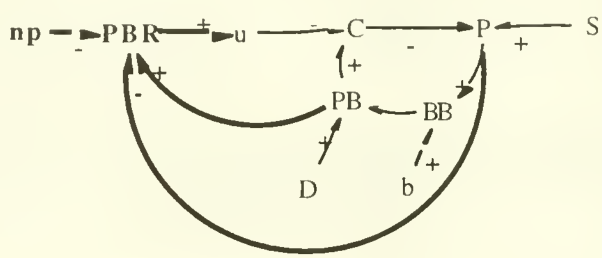


Figure 4: Model 2 with a variable unit project progress cost.

In the new model, the following two equations are added to capture the variability of the unit cost:

$$u(t) = f(PBR(t)) = \alpha + \beta \cdot (PBR(t))^{\lambda} \qquad (9)$$

$$PBR = \frac{PB(t)/P(t)}{np} \qquad (10)$$

In which:

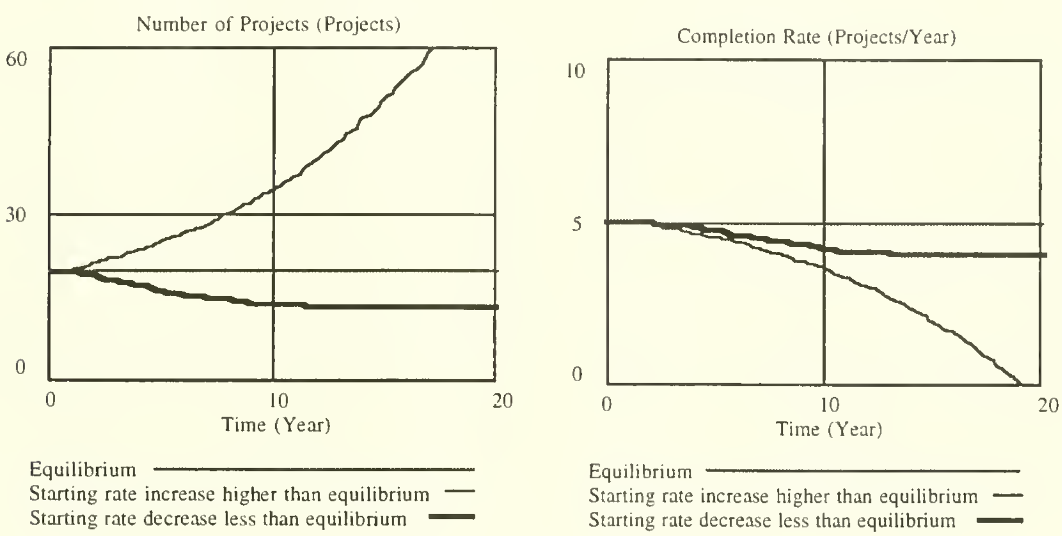
PBR = Progress Budget Ratio (Dimensionless)

np = Normal Annual Progress Budget per Project ($/Year/Project)

α, β, and λ are constants

Equations 9 and 10 indicate that when progress budget per project is at its normal value, then $PBR=1$ and $u=\alpha+\beta$. However, when progress budget per project becomes larger than normal, $PB/P \succ np$ and $PBR \succ 1$, then $u \succ \alpha+\beta$ that means progress cost to complete a unit project becomes more than its normal value. At the extreme when $\frac{PB}{P} \to \infty \Rightarrow PBR \to \infty$ and $u \to \infty$ which means it is impossible to complete a project in zero time.

The new model, consisting of Equations 1 to 4 and Equations 9 and 10, is a nonlinear first order differential equation. It may be solved for specific parameter values with computer simulation using a simulation software such as Vensim [21]. Figure 5 shows the behavior of the model for the following parameter values in addition to those parameter values set for Figure 3: α=.9, β=.1, λ=3, np=.25. The two assumptions that the necessary progress cost to complete a project is 1 and the normal annual progress budget for a project, np, is .25, imply a third assumption, which is that the normal time to complete a unit project is assumed to be 4 years.



5a- Behavior of number of projects. 5b- Behavior of completion rate.

Figure 5: Behavior of model 2 when starting rate deviates from its equilibrium value by a step function.

In the new model, when the starting rate decreases below its equilibrium, the number of projects does not fall exponentially to zero and completion rate does not rise to infinity. When the number of projects falls, the base cost budget drops and the progress budget per project rises and the completion time declines. But, at the same time the progress cost of a unit project rises and does not allow the completion rate to rise to infinity.

Although Model 2 improved the basic model to face a drop in the starting rate, its behavior is not still realistic when the starting rate increases by a step function. Such a rise, as shown in Figure 5, unrealistically causes the number of projects to go to infinity and the completion rate to drop exponentially.

In the real world the starting rate is not disconnected from the state of the system. As the starting rate responds to the condition of the development projects in the system, neither the number of projects nor completion time will go to infinity. In the next section, Model 2 is modified to consider such forces acting on the starting rate.

Model 3: Endogenous Starting Rate

The starting rate of new projects is the most important rate to be decided by those who manage a development budget. On one hand, decision makers are usually under pressure from different national or regional organizations to start new projects in order to foster sectoral or regional development. Due to population growth and a desire to improve the low standard of living, these pressures are high in developing countries. On the other hand, when budget availability for existing projects drops and completion time of projects become too long, social, political, and economic pressures build up to decrease the starting rate of new projects so that existing projects can be completed before new ones are started. As will be discussed later, it turns out that the policy that governs the starting rate decision has a profound impact on the performance of development projects regardless of the quality of management at the project level. The starting rate that influences the performance of the system and is being influenced by that performance, becomes an important endogenous variable in the model.

Model 3, sketched in Figure 6, is developed to capture the starting rate process and the feedback from the state of the system on the starting rate. In Model 3, two new negative feedback loops are added to Model 2 that control the exponential growth of the number of projects and completion time. The new variables and connections in Figure 6 relative to Figure 4 are in bold. The starting rate in Figure 6 is based on a policy under which the starting rate is influenced by an exogenous desired starting rate as well as by budget availability and completion time. The starting rate decision does not have to be made under such a policy. This policy is one possible alternative which might be more broadly exercised, as was the case in Iran according to my observation and experience, and will be examined here. After the consequences of such a policy is discussed, then an alternative policy formulation will be examined.

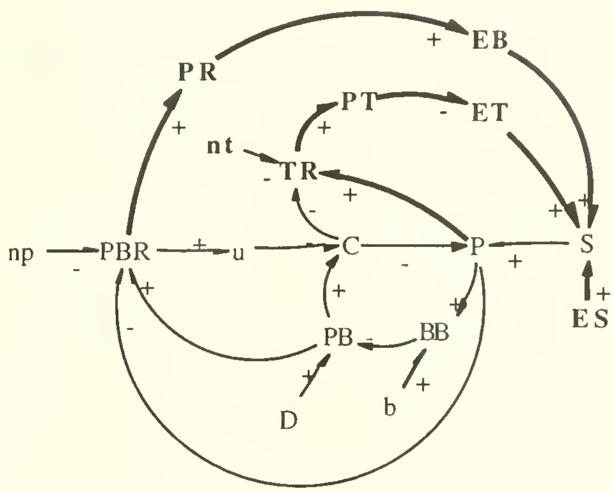


Figure 6: Model 3 with endogenous starting rate.

Equations of the new model consist of equations 1 to 4, 9, 10, and the following equations:

$$S(t) = ES(t) \cdot EB(t) \cdot ET(t) \qquad (11)$$

$$EB(t) = f_1(PR(t)), \qquad f_1^{'}(\cdot) \geq 0; f_1(0) = f_1^{\min} = 0; f_1^{\max}(1) = 1 \qquad (12)$$

$$\frac{d(PR(t))}{dt} = (PBR(t) - PR(t)) / \tau_1 \qquad (13)$$

$$ET(t) = f_2(PT(t)), \qquad f_2^{'}(\cdot) \leq 0; f_2(x \leq 1) = f_2^{\max} = 1; f_2(\infty) = f_2^{\min} = 0 \qquad (14)$$

$$\frac{d(PT(t))}{dt} = (CT(t) - PT(t)) / \tau_2 \qquad (15)$$

$$CT(t) = \frac{P(t)/C(t)}{T_n} \qquad (16)$$

In which:

CT = Completion Time Ratio,

ET = Effect of Completion Time on Starting Rate,

Tn = Normal Completion Time,

PR = Perceived Budget Ratio,

PT = Perceived Completion Time Ratio,

τ_1 and τ_2 are time constants

The starting rate of new projects in Equation 11 is equal to the exogenous starting rate, *ES*, multiplied by the effect of budget availability, *EB*, and the effect of completion time, *ET*. The effect of budget availability, *EB*, is set as an increasing function of the Perceived Budget Ration, PR, in Equation 12. The effect of budget availability is assumed to be bounded between zero and one. When budget availability is zero, EB will be zero to make the starting rate zero. When the Perceived Budget Ratio, PBR, is one or larger than one, EB reaches its maximum at one and does not have any impact on the starting rate. The effect of completion time on the starting rate, *ET*, is set as an decreasing function of the Perceived Completion Time Ratio, *PT*, in Equation 14. Effect of completion time is assumed to be bounded between zero and one. When Perceived Completion Time Ratio is less than one, *ET* will be one to indicate that completion time does not affect the starting rate. When completion time ratio approaches infinity, *EB* reaches its minimum at zero and makes the starting rate equal to zero.

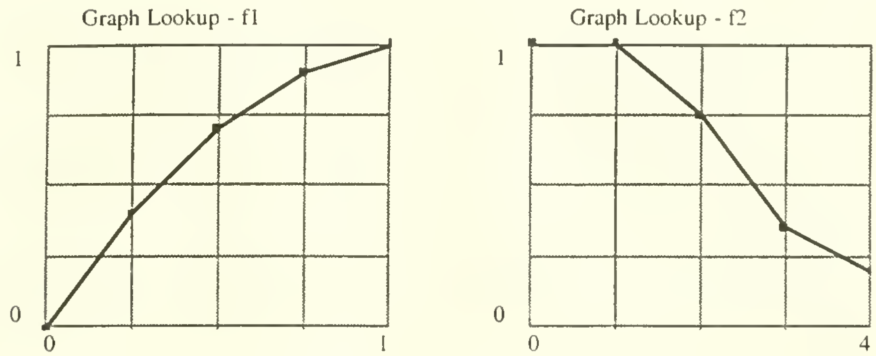
Equations 13 and 15 represent an exponential adaptive process to update the perceived information about budget availability and completion time ratio of the projects. τ_1 and τ_2 are time constants for the two exponential averaging processes. Equation 16 calculates the completion time ratio, *CT*. The numerator of Equation 16 estimates the current completion time by dividing the number of projects by the completion rate. The denominator of Equation 16 is Normal Completion Time.

The overall performance of the system is measured by the ratios of completion time and completion cost of projects to normal or standard completion time and completion cost. The Completion Time Ratio, *CT*, is calculated in Equation 16. The following equation is added to calculate the ratio of the completion cost to the normal completion cost, *CR*. Normal completion cost, the denominator of the equation, is the completion cost of a unit project when progress budget availability, *PBA*, is one and completion time of the project is normal and equal to T_n. The numerator is the actual completion cost, which is equal to unit progress cost, given in Equation 9, plus annual base cost for a unit project multiplied by completion time that is approximated by dividing the number of projects to the completion rate.

$$CR(t) = \frac{u(t) + b \cdot (P(t)/C(t))}{\alpha + \beta + b \cdot T_n} \qquad (17)$$

The new model is a set of third order non-linear differential equations. In addition to the parameter values presented for Model 2, the following numerical values for the new parameters were assumed to solve the model through simulation:

$\tau_1 = 2, \tau_2 = 2, T_n = 4$, all in years. The two functional relationship as shown below:

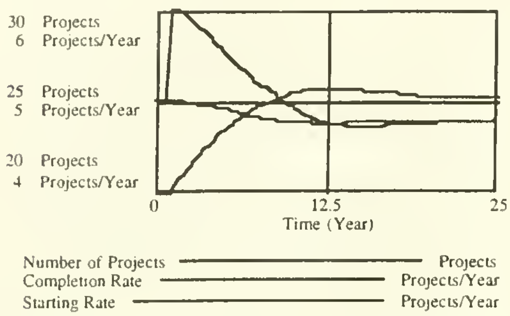


7a. Effect of budget availability as a function of budget availability ratio.

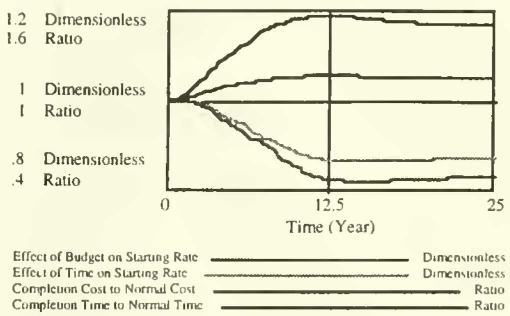
7b. Effect of completion time as a function of perceived completion time ratio.

Figure 7: Functional relationships for simulation.

Figure 8 depicts the behavior of model 3 when the exogenous starting rate is increased from its equilibrium value by a step function at year 1. Figure 8a shows that as the starting rate jumps up above the completion rate in year 1, the number of projects increases. As the number of projects rises, the required base budget increases and less budget will be available for the progress cost. As a result, the project completion rate, shown in Figure 8a, drops and increases completion time of the project. Decline in budget availability and the rise of completion time cause the effect of budget availability on starting rate and the effect of completion time on starting rate, both shown in Figure 8b, to drop. Decline of those two effects would decrease the starting rate after year 1 as depicted in Figure 9a. As Figure 8a shows, when the starting rate drops towards completion rate, the rate of growth of number of projects slows down. The number of projects reaches its maximum at about year 12 when the starting rate crosses completion rate. The number of projects overshoots and then approaches a new equilibrium which is higher than its initial value. As the system moves towards its new equilibrium, the two performance indexes, completion time ratio and completion cost ratio, increase to values above one indicating higher completion time and higher completion cost relative to the normal or standard values. In fact when the exogenous desired starting rate increases above its initial equilibrium, pressures from low budget availability and long completion time force the system to lower the starting rate to become equal to the completion rate and the system settles in a new equilibrium. But the new equilibrium achieved under such pressures is characterized by low efficiency and low effectiveness.



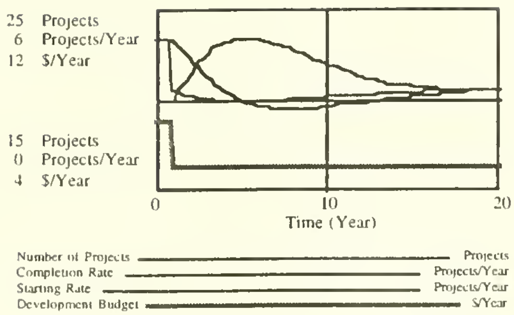
8a. Number of Projects, Starting Rate and Completion Rate



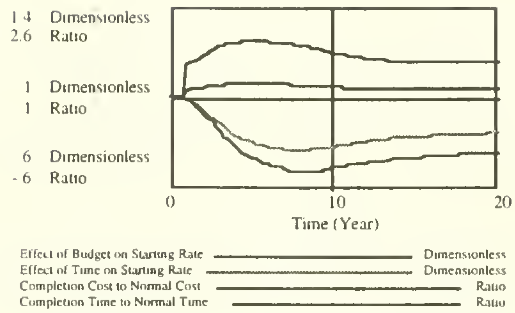
8b. Cost and Time Ratio and Effects of Budget and Completion Time

Figure 8: Behavior of Model 3 as exogenous starting rate is increased by a step function.

There are two points worth mentioning about the behavior of Model 3. First, when the model is disturbed from the initial equilibrium by a step reduction in development budget, instead of a step increase in the starting rate that was done above, the same dynamic characteristic will be observed. Figure 9 shows the behavior of the system when it is disturbed by a 20 percent reduction in the development budget from the initial equilibrium value in year 1. Both the reduction in the development budget and the increase in the starting rate create a shortage of development budget relative to the development projects. The imbalance between the development budget and the development projects pushes the system into an inefficient and ineffective trap under current starting rate policy. In both Figures 8 and 9, in the final equilibrium, budget availability is low and the completion time and completion cost are more than normal. Whether the development budget drop, or the starting rate rises from the initial equilibrium, the system shows the same inefficiency and ineffectiveness. In the real world, development budget systems could be disturbed in both ways. Either an increase in starting rate of the project due to socio-political pressures, or a drop in government revenues due to factors such as change in oil prices, could create the imbalance and disturb the system. Part of the high cost ratio and high completion time ratio of development projects observed in Iran and shown in Figure 1 is the result of such an imbalance.



9a. Number of Projects, Starting Rate and Completion Rate



9b. Cost and Time Ratio and Effects of Budget and Completion Time

Figure 9: Behavior of model 3 as development budget is decreased by a step function.

Second, instability of the system, measured by the amount of overshoot of the number projects and the sustainability of oscillation after the initial disturbance, will increase as the required annual base budget for unit project, *b*, rises. In the above discussion, *b* was .1 or 10 percent of the total progress budget required to complete a unit project. If we increase *b* to .25, the behavior of the system due to a step rise in the starting rate becomes what is shown in Figure 10. With a higher value of *b*, inefficiency and ineffectiveness of the system under the above starting rate policy increases. The next section examines a new starting rate policy to improve the performance of the system.

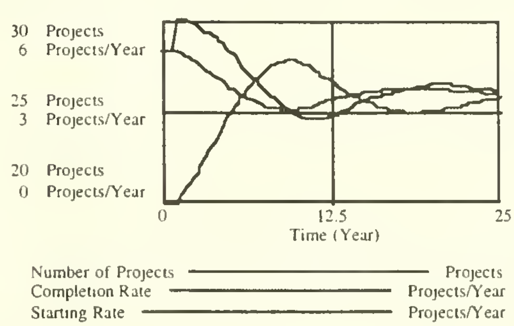


Figure 10: A step rise in the starting rate with high required base cost per unit of project.

Model 4: New Starting Rate Policy

In the previous section, the starting rate was formulated by Equations 11 to 16. In this section, Equations 11 through 15 are replaced with Equations 17 and 18 below, which represent a new policy for the starting rate. The new model consists of Equations 1 to 4 plus equations 17 and 18 to set the starting rate. Equation 16 remains in the new model to calculate the completion time ratio as a performance index. According to the new policy, a desired number of projects, *DP*, is calculated by Equation 18 based on the available annual development budget, *D(t)*, and the required annual budget for a unit project to be completed in normal completion time with the required progress budget available, or *PBR*=1. Then in Equation 17, the starting rate is set equal to the completion rate plus an adjustment term to adjust the number of projects toward the desired number of projects by an adjustment time of τ_3.

$$S(t) = C(t) + \frac{DP(t) - P(t)}{\tau_3} \qquad (17)$$

$$DP(t) = \frac{D(t)}{b + {(\alpha+\beta)}/{Tn}} \qquad (18)$$

In which:

$DP(t)$ = Desired Number of Projects (Projects)

τ_3 = Time to Adjust Number of Projects to Desired Number (Years)

The new model is a first order differential equation. Six main equations of the model can be reduced to the following simple differential equation:

$$P(t) = -\frac{1}{\tau_3} P(t) + \frac{1}{\tau_3} \cdot \frac{Tn \cdot D(t)}{Tn \cdot b + \alpha + \beta} = -\rho \cdot P + \eta \cdot D(t) \qquad (19)$$

In which $\rho = -\frac{1}{\tau_3}$ and $\eta = \frac{1}{\tau_3} \cdot \frac{T_n}{T_n \cdot b + \alpha + \beta}$. The general solution to equation 19 is:

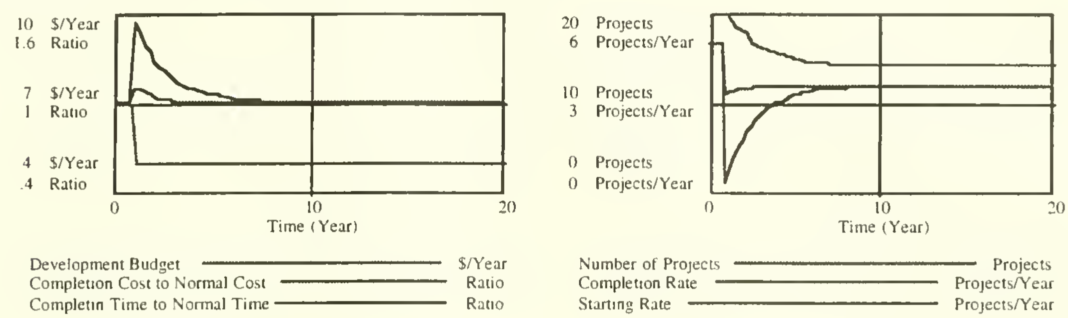
$$P(t) = P(0) \cdot e^{-\rho t} + \int_0^t e^{-\rho(t-\tau)} \cdot D(\tau) \cdot d\tau \qquad (20)$$

Suppose the system starts from an equilibrium in which $P(0) = \frac{\eta \cdot D_0}{\rho}$. If at time t_h the development budget drops by a step function from its initial equilibrium, D_0, to $D_0 - h$, then the solution for *P* after t_h will be:

$$P(t) = \frac{\eta \cdot D_0}{\rho} - \frac{\eta \cdot h}{\rho}(1 - e^{-\rho(t-t_h)}) \quad \text{for } t \geq t_h \qquad (21)$$

As Equation 21 shows, based on the new policy, as $t \to \infty$, $P(t) = \frac{\eta \cdot (D_0 - h)}{\rho}$ which is equal to the desired number of projects for the new level of development budget. At the new equilibrium level, budget will be available to finish the projects at a normal time with a normal cost. During the transition from initial equilibrium to the new equilibrium when the number of project is not yet adjusted to the desired level, the completion time and completion cost will be more than normal. The completion time ratio and the completion cost ratio can be calculated using Equations 2, 16, and 17.

The behavior of the model with the new starting rate policy can be examined by simulation for particular parameter values. Figure 11 shows the behavior of the model with the new starting rate policy when the initial equilibrium is disturbed by a step reduction in the development budget. The parameter values for the behavior shown in Figure 11 are the same as those for the Figure 9 and the value of adjustment time, τ_3, is set equal to 2 years. These parameter values make $\rho = 5$ and $\eta = 1.428$.



11a. Development Budget and Time and Cost Ratio

11b. Number of Projects and Completion Rate and Starting Rate

Figure 11: The behavior of the model with the new starting rate policy.

With the new starting policy, after the disturbance, the system returns to an efficient equilibrium in which the ratios of completion cost and completion time to normal values are one, as shown in Figure 11a. When the development budget drops, the desired number of projects will drop and, as a result, the staring rate, shown in Figure 11b, declines sharply below the completion rate to adjust the number of project, to a lower level. The number of projects, shown in Figure 11b, declines. When the number of projects declines, as Equation 17 dictates, the starting rate begins to rise towards the completion rates. As shown in Figure 11b, as long as the starting rate is less than the completion rate, the number of projects continues to decline. The process continues until the number of projects becomes equal to the desired number of projects. At that point, as Equation 17 indicates, the starting rate and the completion rate are equal, by the way that desired project is defined in Equation 18, there will be enough budget to complete the projects on time and at normal cost. Therefore, as seen in Figure 11a, both the cost ratio and the time ratio become equal to 1 at the equilibrium. Under the new starting rate policy, development projects are completed effectively and efficiently.

Summary and Conclusion

The efficiency and effectiveness of capital investment, in addition to the amount of investment, is the important determinant of growth of production capacity. In a system of development projects where limited resources support ongoing projects, the efficiency and effectiveness of the investment process to create new capacity is influenced by decisions beyond the level of project managers. The starting rate of the new project is one such decision. The starting rate decision changes the balance between the number of projects and available common resources and has important dynamic implications for the efficiency and effectiveness of the investment process. The dynamic arises from the cost structure of the investment projects as presented in this paper.

Investment project cost is divided into two categories: *progress cost* and *base cost*. The *base cost* consists of those cost elements that should be paid to keep the project ready for real physical progress. The *progress cost* consists of those cost elements that should be paid to create physical progress in the projects that are ready for such progress. A unit of project was defined as a project that requires a certain amount of progress cost to be completed at a normal completion time. Each project can be measured in terms of a unit project. The number of projects under construction is increased by starting new projects and is reduced by the rate of completion. The starting rate on the new project is the major management decision in the system.

The cost model shows dynamic implications for the efficiency and effectiveness of projects which are not related to the quality of management at the project level. The paper showed that an imbalance between the common resource and the number of projects moves the system of projects into a trap of inefficiency and ineffectiveness if the starting rate is decided based on exogenous pressure and in reaction to budget availability and completion time. Under such a decision rule, completion cost and completion time of development projects would be more than normal and efficiency and effectiveness of the investment project declines. The paper shows that when the starting rate adjusts the number of projects to a number that is based on available budget, the inefficiency trap can be avoided.

One area of application of this model is the management of development budgets in developing countries. Development budgets represent investments made by governments in different development projects to create infrastructure and production capacity in order to accelerate economic growth and development. Due to population growth and the large gap between the developed and underdeveloped world, there is usually a lot of socio-political pressure to foster development by starting new development projects in different sectors and regions. The pressure to start new projects creates an imbalance between the development budget and the number of development projects. Such an imbalance decreases the efficiency of limited investment resources available to the government of those countries. To increase the efficiency of their scarce investment resources, governments that are responsible for development budgets should make sure that the number of ongoing projects are in balance with available budget.

The application of the result is not limited to the management of development projects, and the common resource is not limited to the budget. The results of this paper are applicable to any situation in which an organization is engaged in a number of simultaneous development projects and a common resource is required by the projects, and each project has *base cost* and *progress cost* in terms of that common resource. The common resource could be management time in managing different projects, programmers' time to create different software, or researchers' time to pursue different research projects.

The responsibility for creating balance between the number of projects and available common resources is above the level of a single project manager. In the case of a development budget, the body that prepares and approves the total development budget has the responsibility of keeping this balance.

The model presented here can be expanded to divide ongoing projects into different stages of development. Such disaggregation can be useful in discussing the allocation of the common resource between different stages of projects during the transition from an unbalanced and inefficient system to a balanced and efficient one.

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