CONSTRUCTION PROJECT MANAGEMENT: A SYSTEM DYNAMICS APPROACH

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ABSTRACT

This study reviews the R&D Project Model developed by Richardson and Pugh III (1981) with a view to apply it to construction project management. Analysis of the model behaviors is done taking into consideration the three prime objectives of project management: meeting specified performance, within cost; and on schedule, and identification of the differences between R&D project model and construction project management is made. Experimentation with the revised model attempts to identify appropriate policies regarding how to improve construction project management.

THE R&D PROJECT MANAGEMENT MODEL

The purpose of the R&D Project Model is to improve the management of R&D projects in such a way as to eliminate or minimize the problems that are commonly observed: cost overrun, schedule delays and poor performance. The authors (Richardson and Pugh III) considered a large project involving a large number of people, a large number of detailed tasks, and a relatively long time frame around four years. They employed intuitions about the structure and dynamics of projects in conceptualizing the model of R&D project dynamics. Similarly, our intuitions about the structure and dynamics of construction projects will help us in conceptualizing the model of construction project dynamics discussed in this paper.

CONSTRUCTION PROJECT MANAGEMENT IN PERSPECTIVE

From inception to completion, project management (construction or otherwise) involves numerous processes, parties and variables which interact and affect each other in varying degrees to determine the time, cost, standard of the end product and the realization of project objectives. Some of the main ingredients for the successful implementation of construction projects are outlined by Wang (1987) as, sufficient and timely supply of:

1. qualified and experienced technical personnel at professional and sub-professional levels;
2. workers: skilled, semi-skilled and non-skilled;
3. materials required; and
4. plant and equipment, and tools for the project.

DIFFERENCES BETWEEN R&D AND CONSTRUCTION PROJECT MANAGEMENT

Our experiences of construction practice suggest that the R&D project model need additions to conform to construction practice. The main differences between R&D project management and construction project management are described below.

1. In the R&D project, the most significant input is manpower only whereas in a construction project, the essential inputs are materials, manpower, equipment and plant.
2. The construction industry in many countries is characterized by a much higher rate of accident than in many other industries (Laufer, 1987; Sidwell, 1990).
3. In the R&D project model, the project cost is mainly the cost of workforce whereas in a construction project, labour, material, equipment and other costs are incurred (Wang, 1987; Chau and Walker, 1988).
4. In a construction project, productivity increases with equipment input (Olomolaiye and Ogunlana, 1989).
5. In the R&D model, there is only one resource of new workforce, whereas in a construction project, the resource of workforce is of two types: new or experienced.

MODEL STRUCTURE OF CONSTRUCTION PROJECT MANAGEMENT

Figure 1 represents, in causal loop terms, the complete structure of the construction project model.

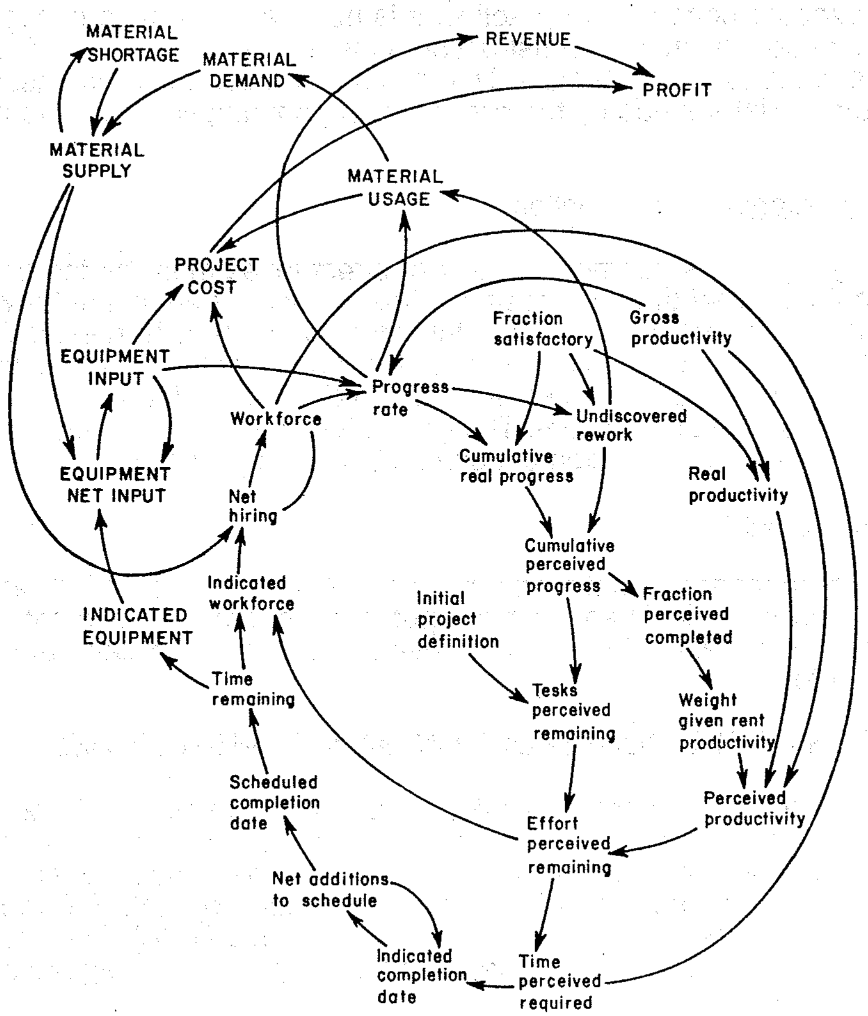

Fig. 1 Complete Structure of Construction Project Model

Basically, the sub-structure of the real progress, the undiscovered rework, the perceived progress and the scheduling sections follow the model developed by Richardson and Pugh III (1981). To enable the model to be used in the construction project management setting, some additions have been made.

The Safety Management Section

The accident generation rate is the product of normal accident frequency, effect of experienced workforce and effect of schedule pressure on accident generation.

The Manpower Management Section

In a construction project, hired workforce can be of two types: new workforce or experienced workforce, depending on the contractor's labor policy and the availability of labor.

The Materials Management Section

The consumption of materials can be categorized into three parts: use for real progress, overuse beyond the designed quantity and use for rework. In order to conform to standard construction practice, it is necessary to have enough stock of inspected materials in the construction jobsite. The quantity of stock of inspected materials can be determined by the consumption over the past months, or it can better be determined by the prediction of consumption over the next few months.

The Equipment Management Section

The necessary input of equipment consist of direct investment by the contractor and equipment acquired through leasing. The quantity of equipment invested is dependent on the contractor's policy. Invested equipment is depleted by the retirement rate, increased by reinvestment rate, and affected by breakdown and repair rates. Most of these rates are affected by the degree of workforce experienced and schedule pressure. The gap between the equipment sought and the current input quantity of equipment can be bridged by leasing.

The Project Cost Section

In the construction management model, the project cost acts as an indicator. The monthly cost can be calculated by the input of workforce, equipment and the consumption of materials. The monthly revenue can also be calculated by the real progress rate.

THE BEHAVIOR OF THE CONSTRUCTION MANAGEMENT MODEL

In order to test the foregoing formulations, a project consisting of 1000 work units was assumed. The number of work units was not allowed to change during construction. In the base run, it takes 46 months to construct this project. Compared to the initial definition of schedule completion by date (40 months), it overruns the initial schedule completion date by 6 months (15%). The behavior of the key variables in the base run of the construction project management model are described as follows.

Progress Rate and the Undiscovered Rework Section

The real progress rate (RPRG) is determined by the inputs of workforce and equipment. The dynamic behavior of the real progress rate (RPRG) is almost the same as the behavior of the input of workforce and equipment. The cumulative real progress (CRPRG) is the integration of the real progress rate. The cumulative undiscovered rework (URW) is determined by the input number of workforce (WF) and the fraction of work that is satisfactory (FSAT). Figure 2 shows the behavior described above.

The Manpower Management Section

The fraction of workforce experienced (FEXP) is the ratio of experienced workforce to the workforce (WF). It is dependent on the inputs of experienced workforce, new workforce and workforce assimilation.

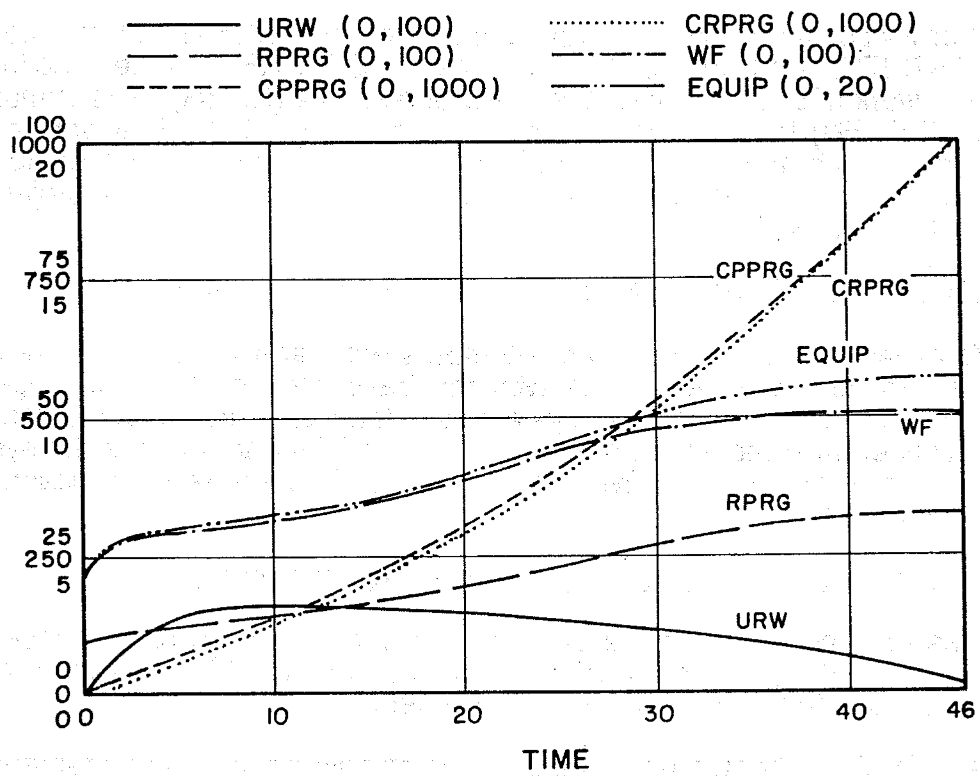

Fig. 2 The Behavior of Workforce (WF), Real Progress (RPRG), Cumulative Real Progress (CRPRG), Cumulative Perceived Progress (CPPRG), Equipment input (EQUIP) and Undiscovered Rework (URW) in the Base Run

The Equipment Management Section

The total input of equipment in the project (EQUIP) is the summation of the equipment invested (EQPINV) and the input through leasing (EQPLES). The behavior of EQUIP is similar to the behavior of workforce (WF). The effect of equipment input on the apparent progress rate (EEQUIP) is the ratio of the input of workforce (WF) to the total input of equipment (EQUIP). In the base run, the

EEQUIP is always not less than 1. It means that the contractor has input enough equipment throughout the project and the input of equipment (EQUIP) is not only responsible for the necessary productivity but contributed additional productivity.

The Materials Management Section

The materials used for real progress (MRPR) has the same behavior as the real progress rate (RPRG). The effect of stock of inspected material (ESIMWF) and workforce sought (ESIMEP) are always 1 throughout the duration of the project in the base run. It means that there is no material supply problem and the stock of inspected materials is enough to meet the material consumption during the project period.

The Project Cost and Revenue Section

The total project cost (TCOST) consists of the labor cost (COSTLAB), the material cost (COSTMTR) and the equipment cost (COSTEQP). The fraction of satisfactory work (FSAT) dominats the real progress rate (RPRG). The cumulative revenue (CREVEN) is less than the total project cost (TCOST) between the 0th month and the 34th month. It is, therefore, worthwhile for the contractor to pay attention to project financial management within this period even if the project will eventually turn in a profit.

EXPERIMENTS WITH THE CONSTRUCTION PROJECT MODEL

Having formulated a base run, several attempts were made to experiment with the model, and to compare the results with the base run, in terms of long-term analysis to gain insights into the system and thus to suggest some feasible policies. Proper implementation of these policies will help to improve the system performance in terms of productivity enhancement without making unreasonable demands on cost and time.

The effect of schedule pressure on construction project management

In the base run, the schedule pressure (SP) is defined as the ratio of indicated completion date (ICD) to the scheduled completion date (SCD); a ratio greater than 1.0 indicating that the project is behind schedule.

In the real life, the schedule pressure is widely translated as a management tool by the jobsite manager without giving considerations to inputs of additional workforce and equipment. This experiment tried to change the definition of schedule pressure only and observed the impacts on the system behavior.

The results of simulations show that high schedule pressure in the construction project causes higher accident generation rate, material overuse rate and lowered the fraction of work that is satisfactory, although it increased the working density. Under current input and management policy, the reasonable schedule pressure do little to reduce the project completion date and increased the project cost a little. It is worth keeping in mind that the higher the schedule pressure is, the worse the system's performance is if the pressure is increased arbitrarily.

The Effect of Experience on Construction Project Management

The fraction of experienced workforce (FEXP) is defined as the ratio of the experienced workforce (EXPWF) to the total workforce (WF). In order to increase the fraction of experienced workforce, the policy can be accomplished through training before the project is started and when construction is in progress. It can also be done by changing the hiring policy, that is, hiring as many experienced workforce as possible. However, it seems more difficult to hire enough experienced workforce without incurring additional costs when the construction industry is booming or, when the project is located in a remote area.

The experimentation represents the hiring policy change; a change in the table function of the effect of hiring policy. Compared to the base run, the experimentation showed that the higher the fraction of experienced workforce (FEXP) involved in the project, the better the system's performance.

Equipment Input and Management

In this experiment, attempt was made to change the equipment investment policy by the STEP function. This experimentation showed that when there is a boom in the construction industry, it is beneficial to increase the investment input of equipment to reduce equipment cost especially if the contractor has a good financial standing and has enough funds to invest in the typical equipment.

In another experiment, it was assumed that the cost per experienced workforce (CPMME) affects the equipment sought (EQPS). That is, in real life, the contractor would like to input more equipment or powerful equipment when he faces labor shortage. Since the effect of equipment on productivity (EEQUIP) is not less than 1 in the base run, increasing equipment input (EQUIP) in this test helped very little to reduce the project completion time. However, it can be practised to reduce the project completion date when the construction industry is faced with acute labor shortage. It can also be a good policy for the government to invest in public construction projects in order to improve construction industry in general.

The Impact of Material Shortage

In this experimentation, the authors used STEP function to test the impact of material shortage on the project. The experiments showed that material shortage causes the stock of inspected material to fluctuate especially when combined with high workforce input and high equipment input to the project. The dynamic behavior described above is shown in Figure 3.

Another experimentation for long term material shortage in this section is the maximum limitation for each delivery quantity. The experiments showed that delivery quantity limitation caused by material shortage is highly sensitive to the workforce hiring, equipment leasing and the project completion time.

SUMMARY

The study has attempted to formulate a construction project management model as an extension of R&D project model by considering requirements of construction project management in the real world. Several experiments are performeded to observe the of various policies on the system behavior. The results of these experiments are summarized as below.

Schedule pressure should be reviewed carefully as a management tool in construction project management. Under current management policy and input, reasonable schedule pressure helps little to reduce the project completion teme: the higher schedule pressure on the project will worsen the system behavior, and increase the project completion date although it increases the working intensity. It also generates more accidents as well as reduce the quality of work.

This model shows the beneficial effect of higher fraction of workforce experienced in a project. Having a professional investigation and proper manpower planning before the project is bid and training program for the workforce prior to project start-up will help goal attainment.

Increased equipment input will reduce the project completion time. Since the project completion time has been reduced, the additional expenditure of equipment input can be compensated for through savings in labor cost. This policy can be practised by inputting newly developed equipment and working methods especially for public construction projects. Furthermore, if the construction industry is booming, remains unchanged or will become better over the coming years, proper increases of equipment investment helps to reduce equipment cost and contribute towards increasing the contractor's profit.

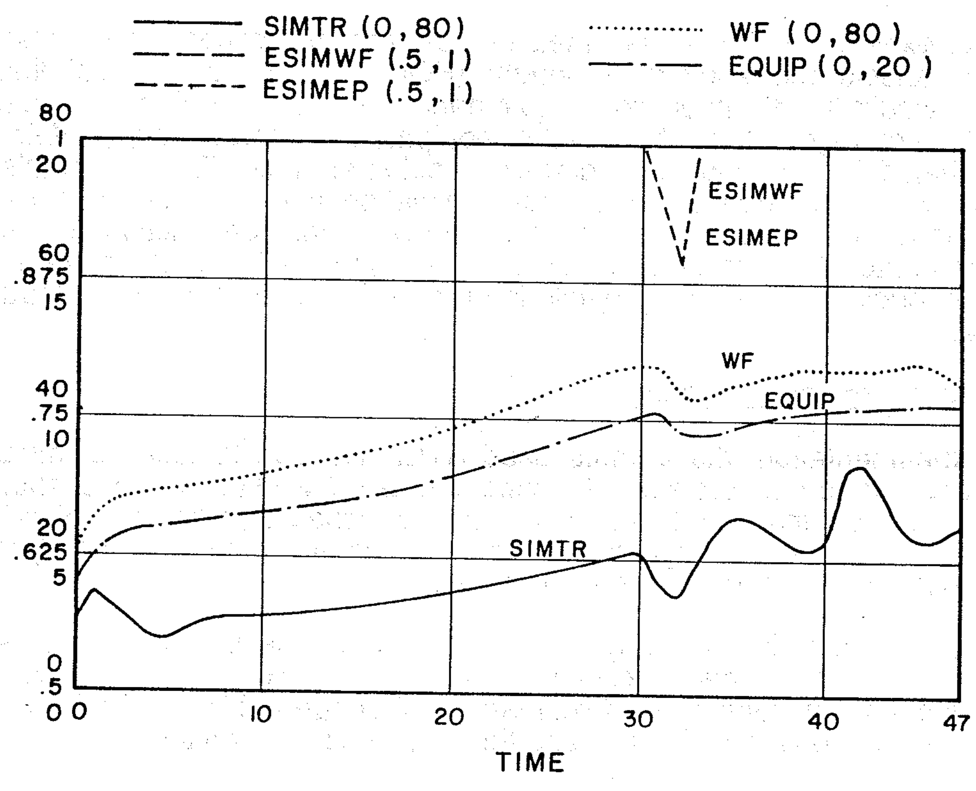

Fig. 3 Dynamic Behavior of Workforce (WF), Equipment input (EQUIP), the effect of Stock of Inspected Material on Workforce Sought (ESIMWF) and the Effect of Stock of Inspected Material on Equipment Leasing (ESIMEP) in rerun (5) Reflect to the Material Shortage

The experiments made in the model show that the input of workforce and equipment cannot achieve their purposes without timely and sufficient material supply. Material shortage not only causes fluctuations in the stock of inspected material but also delays the project completion date when the material demand is high and the material shortage is serious. The experiments also show that delivery quantity limitations caused by material shortage is highly sensitive to the workforce sought, equipment input and the project completion date.

FURTHER EXTENSION OF THE CONSTRUCTION PROJECT MODEL

The model presented is a general phase of construction project management. It outlines the main features of the complex construction management system and can be used as a framework for policy experimentation since it provides insights and concepts into the feedback structure when working under different management problems and policies. However, there are several areas for further detailed study in order to achieve better performance of the construction project management model such as: (1) different categories of manpower requirement and training programs; (2) ways and means to integrate various professions and disciplines with a view to achieving better and more effective teamwork; (3) how newly applied equipment and working methods affect project costs, workforce management during construction, and materials management; and (4) the management strategy related to workforce and equipment input and their interactions.

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