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Designing Software Methodology to Measure the Progress of Projects

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Abstract: Control is an instrument that lets us monitor the progress of what has been programmed and to understand whether there is any deviation or not. In other words, control is the second part of programming and project control and according to the development of projects and increased volume and complexities, it is not possible to be successful without software in different engineering areas such as project control and programming. However in the software of this area, programming has been taken into consideration more than control and only simple procedures have been used regarding control and have formed the basis for project control calculations. Therefore, an accurate methodology based on mathematical rules is needed because in the absence of assessment and accurate control processes it cannot be expected that the program will function. In this study, a new methodology about project control discussion is presented that includes project control stages such as defining the relationships and formula to measure progress, comparison with standards, discovering deviations, determining deviation limits, identifying problems and corrective measures. The relationships and formulas are based on heat conduction in physics where time progress of the activity such as steady state heat conduction and financial progress are similar to unsteady state transmission and accordingly, several relationships have been presented to allow us prepare application suite to be installed on available software and eliminate the weaknesses of project control.

Key words: Project control, project progress measure, methodology, software, weaknesses

INTRODUCTION

It is clear that in project procedure, after decision-making and design, efficient design can provide satisfactory results regarding purposes and hypotheses of the study. However, can modern techniques, methods, accurate design and prediction of various factors lead to the ultimate goal of course the answer is negative because the mental and physical efforts can lead to efficient results when it is possible to show everything in practice. The accuracy and efficiency of planning should be indicated in practice; otherwise, all of them will lead to failure. Therefore, in addition to accurate planning and design, we should attempt to find a way to measure the results and find a solution to deal with problems and deviations. No system can work and achieve its highest capacity without control. All of us are familiar with chaos and delay resulted from lack of control in traffic system. Uncontrolled water or electricity network systems can cause problems or decrease efficiency (Reid, 1999). If a building system is efficiently designed but progresses without any control, it may lead to delays or replacement (Cammann and Nadler, 1976). This study aims to utilize theoretical models and methods in practice to achieve new methodology in project progress measurement. Then, important points in this regard are taken into considerations and finally, theoretical foundations of methodology design are presented.

Statement of the problem: If we consider the project as a mission to achieve certain goals, necessary instruments for this mission are resources and only through correct and on-time use of resources and organization of factors, it will be possible to pass the procedures on time with favorable quality. Only few planning can be found that progress without any problem. Indeed, due to their nature, projects cannot escape from deviation and these deviations, either positive or negative should be carefully investigated. Network, timing and estimation of costs are only predictions and it is not important who has designed them because information from reality are placed into models that never show full similarity to the reality (Bergman *et al.*, 2015). Control is the last step of executive cycle of "planning-governance-control" in project management. In this step, required information are gathered around the system performance are compared with optimal level and if there is difference between real performance and optimal performance the manager decreases deviations. Basically, control process can be defined as follow: action to reduce deviations between the program and reality (Meredith *et al.*, 2016).

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Control concentrates on performance, cost and time. The project manager continuously deals with three aspects. Can the project finish on time? Does the project need more costs? Can the project provide what has proposed? (Rozenes *et al*., 2006).

Real conditions to implement projects are beyond the limited scope of predicted models by managers and planners. In external and internal environments of the project there are forces and drivers that continuously challenge the capabilities and competency of project manager while the behavior and action of these factors are beyond the control of manager. Therefore, network and executive characteristics and technical aspects of the project require modifications when the project stars and information increase (Handzic and Bassi, 2017).

Project control process is more complicated than that was is expected. Moreover, we should specify in which stage of the project, control should be implemented. What should be controlled? How aspects will be measured? How much deviation is acceptable? What kind of interventions should be used? How deviations should be identified and corrected? What kind of control process should be used?

For the project managers, the first step is to set up governance and control system and determination of fundamental factors that should be controlled (Morris, 2013). The manager should clearly and carefully specify that which specific characteristics of projects will be controlled and then determines accurate limits that control will be done within them. Then, method and logics over control process are determined and the control procedure will be assigned to agents.

In valid and available software to control project, this issue has not been taken into consideration seriously and the emphasis has been on project planning. The predicted methods for project control have been formed based on empirical principles or earned values. Generally, it is not possible to criticize competent system that considers project control from the perspective of interaction between various factors. In these software, physical progress of activities is given to the software manually based on user's judgment. However, planning comprises half of project implementation process. Other disadvantages of these methods include the simplicity of problem solving assumptions. Maybe, using these methods, the problems can be easily solved. However, executive operation in construction workshops are accompanied by various factors that include uncertainties (Walker, 2015). Therefore, these methods can provide optimal answers and what is obtained in theory is completely different from reality. According to the proposed issues, it is possible to understand the need to prepare an algorithm based on mathematical rules to provide optimal answers without any shortcoming (Handzic and Bassi, 2017).

MATERIALS AND METHODS

In this study, using project control principles, it will be attempted to create suitable flowchart and algorithm to determine priorities for measurement, conditions and criteria for deviations, measuring deviations, filtering minor deviations and relationship between allocated resources and after case studies, the software package will be prepared (Alam and Guhl, 2016).

Project control: Most of people imagine that governance over project is project control but this is not true. (Eriksson and Lind, 2015) reporting means describing the current condition and what has been happened. Control is to perform necessary measures against content of the report (Fig. 1) (Eriksson and Lind, 2015).

Control concentrates on performance, cost and time. Project manager is continuously engaged in these three aspects. Can the project be completed on time? Does the project need more costs? Can the project provide what has proposed?

Delays in schedule and increased costs compared to the predicted budget may negatively affect the quality and quantity of technical specifications and research purposes. Cost, time and performance can be separately measured with different methods. However, it should be noted that there are complicated and interactional relationships (Chase *et al*., 2004). For evaluation and judgment about management these three factors should be evaluated altogether. The governance process helps the manager in the following cases:

- To identify the relationship between time, cost and performance
- To identify the problems before they happen and implement necessary measures to avoid detrimental effects or decrease them

Therefore, a successful project management system considers reports and shows reaction to each event immediately. Figure 1 shows the components of project control system.

The relationship between progress, time and performance: The relationship between functional components, control process and project stages can be considered as 3D mode. Figure 2 shows this relationship. The project lifecycle is shown on X-axis.

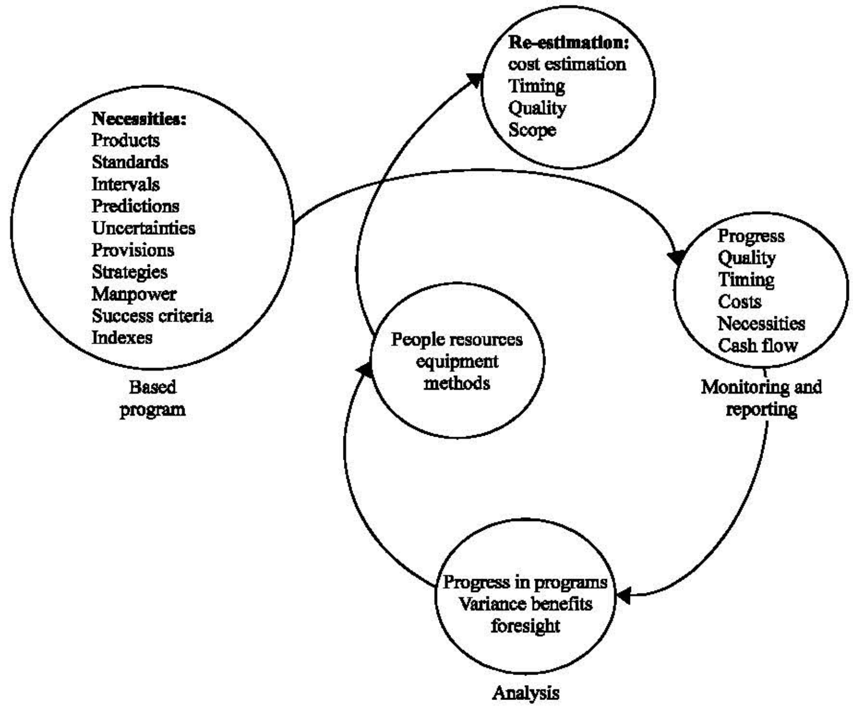

Fig. 1: Project control system elements

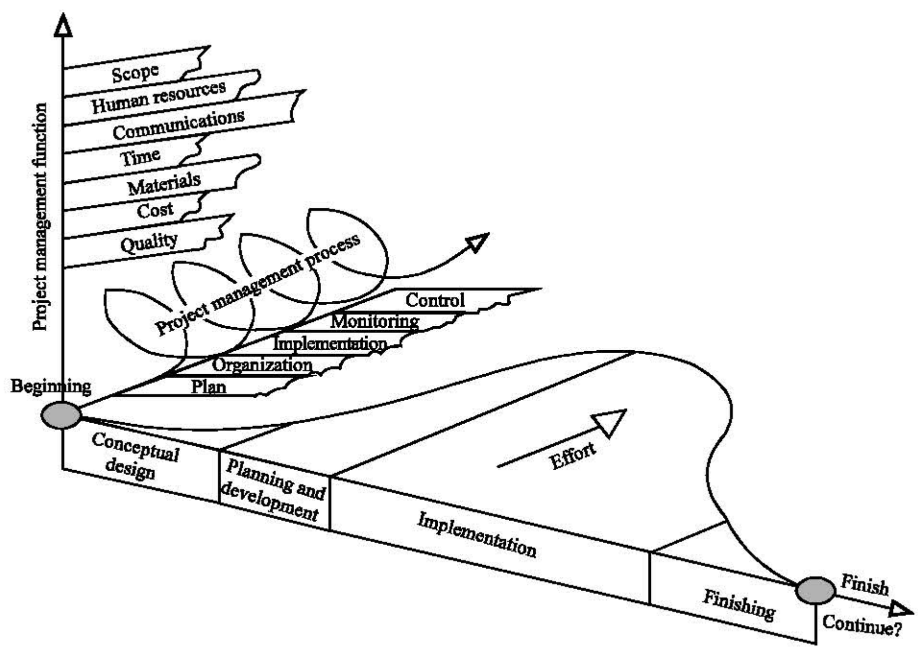

Fig. 2: Sequence and relationship of project control system

On Y-axis, major project performances that should be managed and are important from several aspects are shown. In other words, if the project manager does not take these cases into consideration the project output will not be that optimal. On Z-axis, classic control cycle of input-processing-output will be implemented. It should be pointed that this control cycle should be managed for all major performances, so that by its implementation, it will be possible to achieve project purposes.

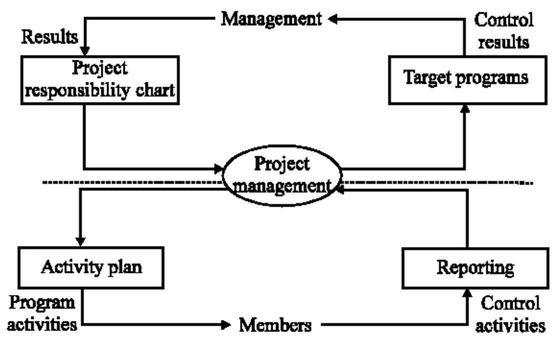

Fig. 3: Integrating control cycle in work breakdown structure

Necessities for effective control: When the work is done, we should make sure that the predicted results are obtained and the possibility to achieve purposes has been provided. The process that studies the progress and uses measures to cope with deviations is called control. For control process, four main steps can be considered (Li, 2016):

- Planning future tasks and estimating performance
- Surveillance and reporting the results
- Comparing the results and predicting future results
- Designing and implementing effective measures to recover the plan or minimize the deviations

The role of project control: A good control program should follow three goals. First, such program must be a true representative of the task and make its implementation possible that is coordinated with the designed programs. Second, this program should provide the possibility to identify, evaluate and predict deviations from the scheduled program. Third, control program should provide the possibility for modifications to coordinate scheduling with the suggested schedule (Meredith *et al.*, 2016).

Control includes both surveillance and updating. Surveillance shows qualitative feedback of the project to specify what happens and predict its future. Updating points out that there are reconsiderations with general consequences and some modifications are required in the network (Avots, 1987). The role of control performance in work breakdown structure can be observed in Fig. 3.

Control processes: Ignoring the purpose of the project, there are three main control mechanisms that can be used: Cybernetic control, Go-No Go control, Post control (Fig. 3).

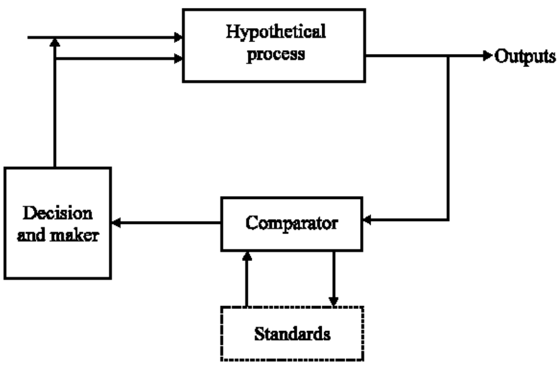

Fig. 4: Cybernetic control process

Cybernetic control: Cybernetic control is the most common system control. The main feature of cybernetic control is that it works automatically. Look at the cybernetic control system in Fig. 4 (Thamhain, 1987).

As can be seen, the system works with input data. These data are exposed to the process that converts them into output. This is the system we aim to control. For this reason, system output should be observed (Avots, 1987). This is done by sensor that evaluates several aspects of output and transfers the results to the comparator. The comparator compares them with a set of predetermined standards. The difference from the standard level is sent to the decision-maker and he determines whether the difference should be corrected and if any measure is needed. If the system output goes away from the standard level, control mechanism works to activate it in adverse direction (Lester, 2017). The velocity or force that the control system works upon it is parallel to standard deviation. The accuracy level that standard level is modified based on it is dependent on the nature of system and controller design.

Direction "A" is direct and rapid but direction "B" is gradual. Direction "C" shows fluctuations with descending range. For example, the airplane that suddenly deviates from the flight path, corrects its path following pattern "B". In this project, cybernetic control has been selected as the system configuration.

Go-No Go control: Go-No Go controls are performed to specify that whether specific pre-condition is estimated. This type of control can be used for each aspect of the project. Regarding many performance aspects, we should know if predetermined characteristics are estimated for the output. This issue is true for cost and time in project plan. Cybernetic controls are automatic and control active systems. But go-no go controls are only used when controllers use them. This approach provides the periodic nature of control but it is likely that tasks deviate from the direction of interest and until the next control, maybe some parts go beyond the control range.

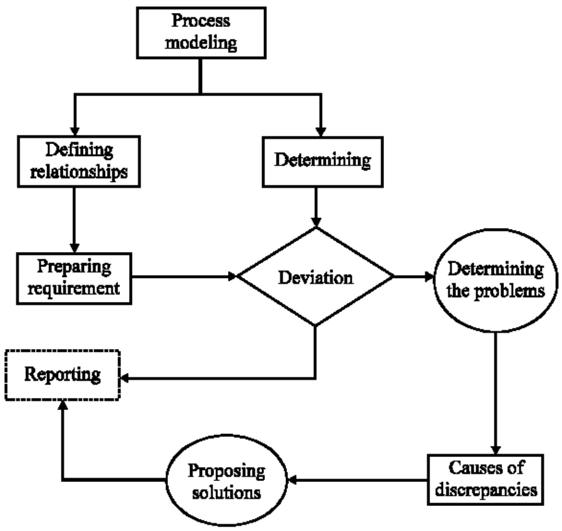

Fig. 5: Algorithm of the suggested system

Post control: Post controls are used after actions of interest. Maybe, some people consider it as treatment after event but this concept does not refer to futile attempt to change what has been happened in the past but it means full admission of what George Santyana sates: "those who have not learned from their past are condemned to repeat it" (Witte, 2007). Cybernetic and go-no go controls aim to satisfy the goals of projects. Post controls are implemented to increase the likelihood to reach the goals of future studies.

Software packages: By software packages it means pre-designed systems or a set of programs or instructions that by implementing certain orders, control inputs to the software package and perform required estimations on them and after selecting the information of interest, print reports (Higgins and Finn, 1976). However, if the user makes mistake in entering the data or instructions the package displays notifications and informs the use and does not allow next operations until the problem is not solved. Most of software packages in these cases provide the user with training set to identify and solve problems.

Suggested modeling for control process

Measurement process modelling: In order to have an effective control over the procedure and based on cybernetic control theory, we have obtained a model to control projects that its flowchart can be seen in Fig. 5 (Smith and Gupta, 2005).

Defining mathematical relationships: In physics, we have heat conduction theory and the designer of methodology measurement process has based his intellectual foundations on it. This theorem is defined as follow.

We consider a piece of hypothetical object where two parallel surfaces with the distance of Δs have cut it. We suppose that thermal energy for one surface is u and for another surface is $u+\Delta u$ (Leinhard, 2013). Experiments show that heat conduction is transferred from hot surface to cold surface and its value in each time unit from each surface unit is obtained by Eq. 1:

$$Q = k\frac{\Delta u}{\Delta s} \tag{1}$$

Here, k is heat conduction coefficient. If the distance between surfaces decreases, it means that Δs moves toward zero. Therefore, according to the definition of derivative, we have Eq. 2:

$$\lim_{\Delta s \to 0} k\frac{\Delta u}{\Delta s} = k\frac{\partial u}{\partial s} \tag{2}$$

The result provides the value of heat conduction per second in surface unit perpendicular to the s direction and $\partial u/\partial s$ specifies heat change speed in s direction. Now, we suppose that initial heat degree is defined by the following function:

$$u = f(x, y, z)$$

We aim to find heat degree in each t moment. Function u that provides heat at t, should satisfy the following relative differential (Eq. 3):

$$\frac{\partial u}{\partial t} = \frac{k}{c\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{3}$$

In Eq. 3 c, ρ and k are heat coefficients of the object, density of the object and heat conduction coefficient, respectively. Equation 3 has been obtained according to this assumption that k, c and p are independent from u. It is easy to prove that if the initial conditions are clear, heat determination problem at each time of interest (t) has a solution. It should be noted that to model the present methodology, other limiting conditions of model such as thermal energy radiation of the object of thermal isolation and similar cases are ignored.

The last point that should be noted is that if the conduction is in steady state, so than u is independent from t, we have $\partial u/\partial t = 0$ and Eq. 4 will be as follow:

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial^2 z}=0 \tag{4}$$

This is known as Laplace and is observed in physics.

Steady state heat conduction: The first part of heat conduction in physics is considered as the basis for methodology. Description of this theorem goes as follow. We considered a rectangular plate with the width of d that one side is exposed to u1 and the other side is exposed to u2. If one side matches yz surface, conditions on the surface will be as follow.

If x = 0, then u = u1 and if x = d, we have u = u2. In this condition, the heat of u should satisfy (Eq. 4). Here, it has been assumed that the plate of interest has irregular dimensions in y and z axes. Therefore, it is clear that u is independent from y and z and Eq. 4 will be changed to the following case (Sabul, 2012):

$$\frac{\partial^2 u}{\partial x^2}=0 \tag{5}$$

It easily to determine the solution for Eq. 5 as follow:

$$u=c_1 x+c_2 \tag{6}$$

C_1 and c_2 are constants. By inserting x = 0 and x = d in Eq. 6, we conclude that $u_1 = c_2$ and $u_2 = c_1d+c_2$. Therefore, problem solving will be as follow Eq. 7:

$$u=\frac{u_2\text{-}u_1}{d}x+u_1 \tag{7}$$

Considering heat conduction value in each second of plate surface unit, we have the following Eq. 8:

$$k\frac{\partial u}{\partial k}=k\frac{u_2-u_1}{d} \tag{8}$$

It is observed that heat conduction value in t from surface A equals the following Eq. 9:

$$Q=\frac{k}{d}(u_2\text{-}u_1)tA \tag{9}$$

Variable heat conduction: Capital injection to work packages of a project is similar to heat conduction in a hypothetical object because it does not have uniform trend with similar velocity. Also, according to the fluctuations of that work package, different amounts of financial resources can be allocated. Here, the second part of heat conduction conduction in physics is considered according to methodology planning in cost area. This study is stated as follow. Consider a wire with the length of l. Is assumed that its longitudinal surface is heat insulator. Heat degrees of two ending sections are constant. At t = 0, heat conduction in length is determined by u = f(x). The problem of interest is to determine point heat degree as the length of x on wire in t. In this case, u is the function of distance of point on the wire and t and if the wire is located on x axis, Eq. 3 will be as follow:

$$\frac{\partial u}{\partial t}=\alpha^2\frac{\partial^2 u}{\partial x^2} \tag{10}$$

Solving u from the above equations not only should satisfy Eq. 10 but should satisfy the following parallel conditions:

$$\begin{array}{ll} \text{If } u=10 & u=0 \\ \text{If } u=10 & u=0 \\ \text{If } u=f(x) & u=f(x) \end{array}$$

We assume that solving Eq. 10 is resulted by multiplication of two functions of x and t. Therefore:

$$u=X(t)T(t)$$

By inserting this in Eq. 10 the following is obtained:

$$\frac{1}{\alpha^2 T}.\frac{dT}{dt}=\frac{1}{X}.\frac{d^2X}{dx^2} \tag{11}$$

This equation will be valid when both sides of the equation are equal to constants such as $-\beta^2$. Therefore, the following is concluded:

$$\frac{dT}{dt}+\alpha^2\beta^2T=0 \text{ and } \frac{d^2X}{dx^2}+\beta^2X=0$$

Linear independent solutions for these ordinary differential equations will be as follow:

$$T=e^{-\alpha^2\beta^2t}$$
$$X=\text{Cos}\beta x$$

Since, u = TX, the potential solution for u is:

$$u = e^{-\alpha^2\beta^2 t}\,\mathrm{Cos}\beta x \qquad (12)$$

This solution does not satisfy the first boundary condition. Therefore, if β = nπ/1 and if n is an integer, we have:

$$u = e^{-\alpha^2\left(\frac{n\pi}{1}\right)^2 t}\,\mathrm{Sin}\frac{n\pi}{1}x \qquad (13)$$

Then:

$$u = \sum_{n=1}^{\infty}\left(\frac{2}{1}\int_0^1 f(x)\,\mathrm{Sin}\frac{n\pi x}{1}dx\right)e^{-\alpha^2\left(\frac{n\pi x}{1}\right)^2 t}\,\mathrm{Sin}\frac{n\pi x}{1}$$

Equation 13 has satisfied all conditions and is the optimal solution of the problem.

RESULTS AND DISCUSSION

Relationships governing the methodology: In each interval of investigating time and cost, several relationships are presented that have been formed according to the formation basis of methodology and will be described in the following. The theoretical foundation of these relationships are based on heat conduction.

Time: In this area that is measuring time performance of work packages, four major relationships are presented. The first relationship is to investigate the relationship and difference between real time and program time of an activity. We know that the basis to measure project progress should be according to the time framework and if these are measured separately the results cannot be valid. Therefore, if time is considered as independent variable and the difference between the area of program progress curves and real progress curves is measured each time, two facts can be understood easily: activity progress norm based on its time and reduction. Delay, share of delay and the effect of delay on the current process of the activity:

$$A = \int_{t_1}^{t_2}\left(AD_n - SD_n\right)dt \qquad (14)$$

For this purpose, real and program progresses are extracted by periodic reports and their axes are drawn by plotting. The second relationship in this area investigates real progress of each activity and predicted progress in performance and provides a criteria regarding various velocity levels. Therefore, if instantaneous velocity of activity progress is less than average velocity for that this activity should be investigated. For this purpose, average progress of each work package is calculated and then, using the obtained axes, time-based progress derivation is calculated, too. Then, two resulted numbers are compared and wherever the progress derivation is smaller than average progress that interval is the location of problem in progress procedure of the work package of interest:

$$B: \frac{dP_n}{dt} \qquad C: \frac{\Delta P}{\Delta t} \qquad (15)$$

Since, this relationship unlike other relationships that look at activity generally, aims to identify the whole activity it can measure all activities and highlight critical moments.

The third relationship that is the most important one aims to measure each activity. We know that the first derivation indicates its changes and the second derivation indicates concavity of the function. If first and second derivations of f(x) are indicated by $f'(x)$ and $f''(x)$, four conditions can be considered for the function:

- $f'(x)$ and $f''(x)$| are positive: the function is concave and ascending
- $f'(x)$ and $f''(x)$ are negative: the function is descending and convex
- $f'(x)$ is positive and $f''(x)$ is negative: the function is ascending and concave
- $f'(x)$ is negative and $f''(x)$ is positive: the function is descending and convex

Conditions 1 and 2 lead to changes in function with severe rates. We know that multiplication of two expressions with similar signs will be positive. Therefore, if in different time intervals, the following conditions is obtained, the activity should be investigated. In the first stage, we determine an index to investigate the changes in time-progress function. For this purpose, we define a function that is the result of multiplication of the first derivation in the second derivation of progress function based on time. Then in each time interval, the values are investigated to determine negative values in different intervals. Finally, it can be concluded that in these intervals, the progress of work package is faced by problems:

$$D: \frac{dP_n}{dt}\times\frac{d^2P_n}{dt^2} \qquad (16)$$

This equation does not include holistic view. Also, after drawing the axis it easy to identify time intervals where problems were faced and this leads to time saving. It should be noted that it is possible to predict orders in software and investigate the measures using the axis. Progress of each activity requires resources. Therefore, measuring progress without considering resource consumption leads to challenges for measurement because changes in rate and velocity in an activity affect other activities (Walker, 2015). Accordingly, the fourth equation aims to measure the progress of activity considering resource consumption. In this regard, if multiplication of these two factors is <1 it shows lack of uniformity that demands investigation of the activity:

$$D: \frac{dP_n}{dt} \times \frac{d(RC_n)}{dt} \quad (17)$$

Cost: According to the conditions in heat conduction model in steady state, we describe the relationships in cost area. This relationship investigates the relationship and difference between predicted costs and real costs. We know that the basis to measure financial progress of the project should be according to the time framework and if these are measured separately, the results cannot be valid. Therefore, if time is considered as independent variable and the difference between the area of program progress curves and real progress curves is measured each time, two facts can be understood easily: activity progress norm based on its time and ascending and descending modes. Differences in real and program costs their share and their effectiveness in activity procedure:

$$E = \int_{t_t}^{t_2} \left(AC_n - SC_n\right) dt \quad (18)$$

The third advantage of the relationship is the ability to measure difference in cost in each interval. In this condition I(t) can be a new function and measures its descending or ascending changes. However, it should be pointed out that if software package of control measurement is prepared, other suggested relationships that are based on heat conduction theorem will be used. These relationships are as follow.

This relationship aims to measure the difference between activity cost and predicted costs in program and total costs in project. However, upper and lower limits should be defined for reasonable measurement:

$$F = \frac{\left|AC_n - SC_n\right|}{DTC_T} \quad (19)$$

Another index for cost problem measurement is investigation and prediction of costs for an activity with respect to average cost. Indeed, when the activity is finished, we estimate real costs and the compare the results with predicted costs in the program:

$$C_f = W_T.ACE_t \quad (20)$$

The next relationship measures the dependency of activity progress on natural resources consumption and financial resources consumption:

$$K = \frac{dP_n}{dMC_n} \times \frac{dMC_n}{dt} \quad (21)$$

Accordingly, if multiplication index is not uniform in time interval, it should be investigated. This relationship indicates relative changes and dependency of two progress functions on financial resources and consumption of financial resources based on time. One of the advantages of this relationship is simultaneous measurement of progress, cost and accuracy.

The last index about measurement of cost problem concentrates on prediction and investigation of costs with respect to consumed costs and remained working units and expected costs in each interval. Indeed, before the end of the activity we estimate real costs and compare the results with the predicted costs in program:

$$C_f = C_t + \left(W_T - W_L\right).CF_L \quad (22)$$

One of the advantages of these indexes is that activities that are accompanied by risk are highlighted in costs before the end of the activity.

Determining the deviations: After defining the relationships and obtaining general framework of progress measurement, deviations should be determined. In this stage, we should point out what deviations are occurred during activity and which deviations are significant (Carter and Smith, 2006). All deviations that are likely to occur in measurements are summarized in Fig. 6.

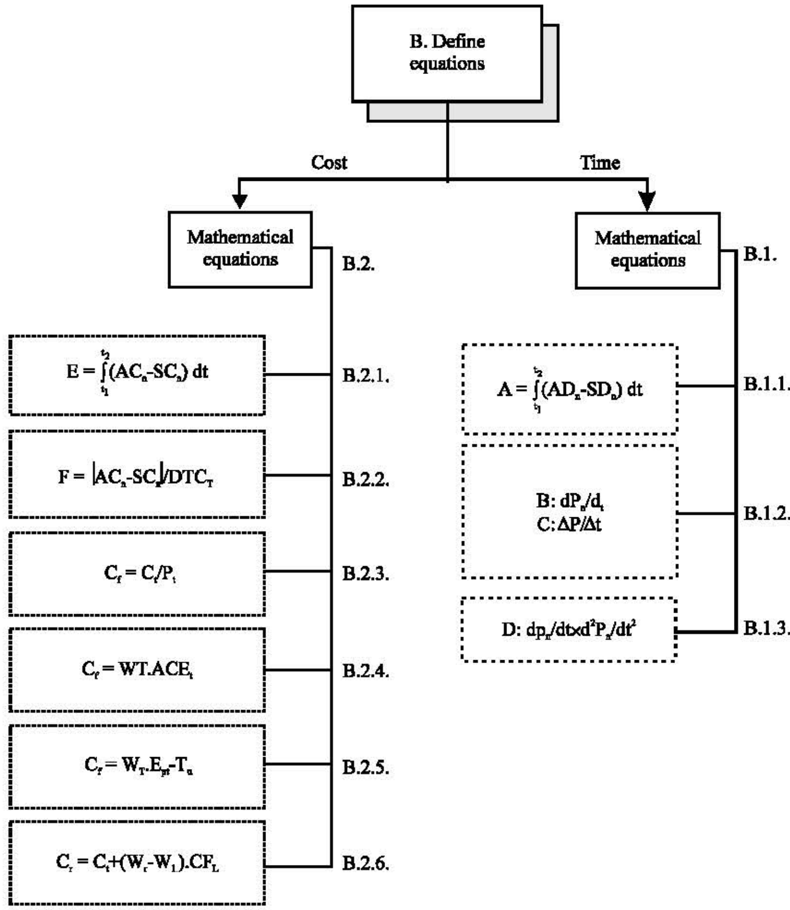

Fig. 6: Relationships and formulas governing methodologies and profiles; ACEt: Average Cost Experience till time t; ACn: Actual Cost; ADn: Actual Duration; C_f: Cost forcast; CF_L: Cost Forcast for Left activities per time unit; C_t: Total cost consumed til time t; d_i: Delay in start nodeof an activity; d_j: Delay in finish nodeof an activity; d_n: Delay of an activity; dT: Project delay; DTC_T: Deviation of total cost; E_{pt}: Experience per unit time; Et: Efficiency till time T; FdT: delay in finish of project; Ffn: Free Float; IFn: Independent Float; Mcn: Mony Consumption; P(t)n: Progress of activity; RCn: Resource consumption; SCn: Scheduled cost; SDn: Scheduled Duration; SdT: Delay in start of project; TCT: Total cost of project; TFn: Total Float; Tu: Time unit; WL: Unit of work Left; WT: Total Work units

CONCLUSION

The necessities to have effective control over project consist of accurate criteria for measurement and by popular software, it is easy to understand activity progress measurement is simple. Therefore, in most of Software packages, the user is asked to insert a number between 0 and 100 and the software considers inaccurate number as the basis for future calculations. Since for each activity, time and cost resources are consumed, the progress level should be measured with respect to resources and time consumptions. Therefore, we need to design a fundamental method to calculate activity progress with high accuracy. In this study, first, foundations and the necessity to control project were proposed and new algorithms were presented to measure the progress of projects. In this algorithm, some stages are predicted that include determination of measurement relationships, limitations of deviations, discovering significant deviations and identifying problems (Carter and Smith, 2006). In order to define the relationships based on simulation of project environment that is known as heat conduction theorem, some formulas are suggested to measure activity progress in terms of time and cost and it is expected to investigate all factors in activity procedure. In these formulas, activity time progress procedure is considered as heat conduction in steady state and capital injection and financial progress are similar to unsteady state heat conduction.

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