African Research Review

*An International Multi-Disciplinary Journal*

***ISSN** 1994-9057 (**Print**)* ***ISSN** 2070-0083 (**Online**)*

**Volume 2 (4) September, 2008** **Special Edition: *Engineering***

# Time Planning for Construction Projects: Conceptual Developments

*(pp. 88-112)*

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**Abstract**

*Time planning passes through four conceptual development stages. These are Bar Chart, Network Diagram, Resources Constrained Project Scheduling (RCPS) and Time Planning under Uncertainty. Recent developments acknowledged uncertainties in time planning and categorized them in four major factors. They are Uncertainties of Detailing of Activities, Estimating Activity Durations, Resources Dependencies, and Task Dependencies specifically Merge Event Biases (MEB). As a result, CPM, PERT, Mathematical and Heuristic models, Monte Carlo Simulation, Successive Principles and Theory of Constraints (TOC) are developed for Time planning approaches. This paper tries to review these conceptual developments for use in Practical applications and for R&D.*

**Key words:** Time planning, CPM, PERT, MCS, Successive Principle, Theory of Constraints

## Introduction

Time planning is important in construction projects. This is because time is one among the Triple Constraints in which the performances of construction projects are evaluated with. That is; if a project is delayed from its completion time; the intended objective of the project could not be achieved; it affects the second component of the Triple constraint which is "Cost" to cause substantial cost overruns; and if appropriate technological time requirements are not adhered, the quality of the product will be under question which is the third component of the Triple constraint. This paper therefore addresses the conceptual developments of time planning in an organized manner such that practitioners are aware and update their knowhow.

## Time Planning

It has been long since the recognition of 'time value of money' worldwide. As a result, time planning for construction projects has been practiced for several decades. The conceptual development of time planning can be placed under four major developments. These are:

1. Bar Charts
2. Network Diagrams: CPM and PERT
3. Resources Constrained Project Scheduling
4. Time Planning Under Uncertainty

## Bar Charts

Time planning of projects was first practiced using Bar Charts. Besides, Bar Charts are still in use due to their simplicity for practitioners to produce them. They are used either by themselves or twined with CPM and PERT systems.

Bar charts show activities vertically and their schedules horizontally. Such scheduling tools can only show when activities can be carried out, which activities are behind schedule and their progress to date. J.

Shi & Z. Deng [2000] noted that these charts can't show the logical inter-relationships among activities called ***task dependencies***.

Besides, if an activity is behind schedule, it is difficult to determine its effect on the completion of the project. However, this type of scheduling or time planning technique is the practice for most public construction projects in Ethiopia until today [Wubishet, 2004].

**Network Diagrams: CPM and PERT**

Network Diagram is a response to the drawback of Bar Charts in which three types of graphic representations (Figure 1) are developed in order to show task dependencies. These are Activity on Arrow (AOA), Activity on Node (AON) and Precedence Diagram (PD). Due to the development of information technology using computer, the later approach (PD) became popular and is widely used.

The most useful contribution of these Networks are *CPM* (Critical Path Method) and *PERT* (Program Evaluation Review Techniques) techniques. These techniques deal with the following questions:

- when will the project be completed?
- what are the critical activities, if delayed could affect the completion time? and
- how late can non critical activities be started without affecting the completion time?

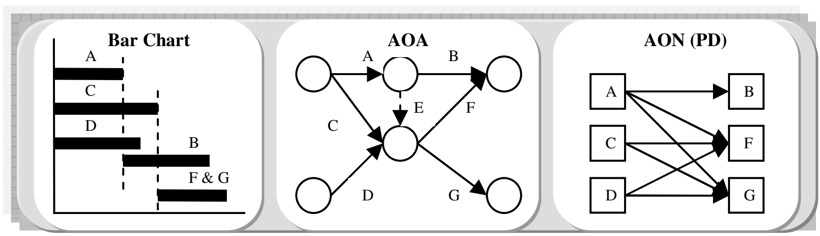


**Figure 1: Three ways of representing task dependencies**

They both also share the following six basic steps (Box 1) in dealing with the above questions.

**Box 1: Six basic steps for CPM & PERT**

1. Define activities (WBS);
2. Determine Precedence Relationships among activities;
3. Estimate time required to accomplish each activity;
4. Draw network and label necessary information;
5. Compute Forward and/or Backward Pass time values to determine the Floats or Slacks and the Critical Activities; and
6. Use the result to plan, monitor and evaluate time performances.

The difference between these two methods (CPM and PERT) lies on the third step when the duration of activities are estimated. That is, while CPM uses deterministic or single time estimates for the activities, PERT uses probabilistic values of triple estimates ($t_{bc}$, $t_{ml}$, & $t_{wc}$) for the variations of activity durations (ie; stochastic approach).

PERT assumed Beta distribution function that estimates the mean 'μ' and the variance 'Var' using expressions given in Eqn 1.

$$\mu = (t_{bc}+4*t_{ml}+t_{wc}) / 6; \ \& \ Var = (t_{wc}-t_{bc})^2 / 36 \quad \text{(Eqn. 1)}$$

Where, $\mu$ = Expected duration of activities
Var = Variance
$t_{bc}$ = Best case estimated duration of activity
$t_{ml}$ = Most likely estimated duration of activities (Mode)
$t_{wc}$ = Worst case estimated duration of activities

Using such expression for PERT was not without problems. These included; the choice of Beta distribution itself, the difficulty to estimate $t_{bc}$ and $t_{wc}$ values and the exclusion of catastrophic events from worst case ($t_{wc}$) time estimates. This will further be complicated



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when each and every activities of the project are considered for time planning. Whatever the case, PERT only considers one aspect of uncertainty in time planning, that is; uncertainties due to estimating activity durations only.

Later researchers using beta, gamma, and lognormal ([Klastorin, 2004] - Eqn. 2) and Erlang distributions ([Austeng, 1994] - Eqn. 3) together with different fractile approach to the three estimates suggested expressions that can give better approximation for $\mu$ and $\sigma = \sqrt{Var}$ as;

$$\mu = (t_5 + 0.95 * t_{ml} + t_{95}) / 2.95; \text{ and}$$
$$\sigma = \sqrt{Var} = (t_{95} - t_5) / 3.25 \quad \text{(Eqn. 2); and}$$
$$\mu = (t_1 + 2.95 * t_{ml} + t_{99}) / 4.95; \text{ and}$$
$$\sigma = \sqrt{Var} = (t_{99} - t1) / 4.6 \text{ (Eqn. 3)}$$

Where, $\mu$, $\sigma = \sqrt{Var}$ and $t_{ml}$ are the same as given in PERT

$t_{1 \text{ or } 5 \text{ or } 95 \text{ 0r } 99}$ = 1 or 5 or 95 or 99 percentile estimated duration of activities

Besides; while some empirical evidences showed that estimators are better in estimating central fractiles, others claimed for extreme values. There are also instances researchers tried to adopt five and seven estimate approaches but we understood such increments can only add complexities to estimators and their accuracies are very doubtful. As a result, random variables using Monte Carlo Simulations (MCS) are considered better for task duration estimates.

These two methods were seldom practiced in Ethiopia. The major reasons were noted as:

- lack of emphases to use CPM & PERT methods,
- complexity & difficulty of using CPM & PERT manually,
- lack of inputs to feed modern computer software's, and
- lack of skilled professionals [2].

Furthermore, the network of activities will change several times during implementation requiring the review of CPM and PERT several times too.

The CPM scheduling approach did not consider such uncertainties and changes with an assumption that resources are abundantly available for all project activities whenever they are required. Subsequently, the early and late dates are calculated using an algorithm based on estimated constraints built logically and technologically among activities deterministically.

That is, CPM took into consideration that there is smooth continuity between successive processes and assigns the maximum Finishing Time (FT) among the predecessors to the Starting Time (ST) of the following activities (Figure 3 & Eqn. 4).

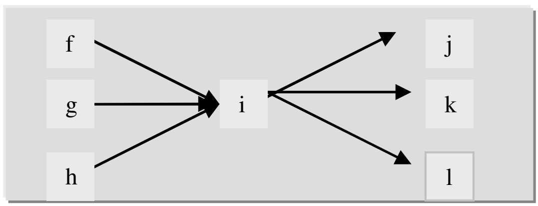



Figure 2: Merging & Diverging activities using CPM

$$ST_{i - j, k, l\ldots} = \max (FT_{\ldots f, g, h - i}) \text{ ------- (Eqn. 4)}$$

Where, $ST_{i - j, k, l}$ = Starting time for Activities i - j, k, l,

max $(FT_{\ldots f, g, h - i})$ = maximum of Finishing times among activities …f, g, h – i

But most studies in real life practices indicated that constrained resources and issues related to multitasking prevail. Consequently, time planning required to consider resource dependencies and the issue of parallel and near critical activities called Merge Event Biases (MEB). However these requirements could not be dealt either by CPM or PERT approaches alone.

In both these methods the target is to determine critical activities and to give priority and attention to them because they are identified as determining activities which can affect the total project completion time. That is, project managers should give priority and higher importance to such activities to prevent project delay. These activities are determined using the Earliest and Latest Start and Finish times of activities when their difference are zero; that is, there are no slack times for the project along a path called the critical path.

**Resource Constrained Project Scheduling**

The issues of Resources scheduling had also received several attentions using either Time- or Resources- Constrained approaches [Abeyasinghe, Greenwood and Johansen, 2001]. Both methods start with CPM or PERT assuming there is no resource problems and then considers the issue of resource constraints afterwards.

While Time Constrained resource scheduling considers fixed completion time and use of resources aggregation, smoothening and leveling within the available slack or float times; Resource Constrained scheduling first investigates the potential of using resources within the total float of activities and altering their sequences, then and only if necessary that, it considers increasing the project duration. Following this, so far two methods have been promoted; Optimization using Mathematical Programming Models and Heuristic (Rule of Thumb or Common Sense) Techniques.

While Mathematical Optimization Models accepts the shortest project duration or the one which provides the smoothest resource profile as the optimum time of activities; the Heuristic approaches allows a process of choosing among activities for the use of scarce resources.

Heuristic algorithm techniques are based on criteria for prioritisation. For instance, studies made prioritizations based on nine alternatives revealed that those based on Lowest Total Float Time, Latest Start Time and Descending Activity Duration provided the shortest project duration.

Other prioritizations used include:

- ACTIM: Maximum time the activity controls throughout the critical path network;
- ACTRES: Maximum sum of products of time & resources that the activity controls throughout the network;
- TIMRES & GENRES: Weighed combinations of ACTIM and ACTRES values;
- ROT: Maximum sum of the ratios of resources to time;
- ACROS: Maximum resource that the activity controls through the network;
- TIMROS: Weighed combinations of the ACROS and ACTIM values; and
- TIMGEN: Weighed combinations of the TIMROS and GENRES values.

Elsayed and Nasr [1986] using such prioritizations on a single project under single resource constraints showed that TIMROS and TIMGEN provided the shortest project duration. Other studies using Minimum Job Slack (MINSLK), Resource Scheduling Method (RSM), Minimum Late Finish Time (MINLFT), Greatest Resource Demand or Utilization (GRD/U), Shortest Jobs Operation (SJO), Most Jobs Possible (MJP) and Select Jobs Randomly (RAN) showed that MINSLK, MINLFT and RSM heuristic techniques delivered the shortest project duration.

These heuristic methods; whether they are carried out manually or using computer aids, could not give the optimum solution for resources constraints. Besides, their increase in complexity and lots of computations did not encourage their use in the practical world. These techniques have not been practiced in Ethiopia and also found impractical as their computation could not guarantee optimization worldwide. As a result, they were remained under the consumptions of Academic or R&D services only.

**Time Planning Under Uncertainty**

Development in time planning so far, though addressed uncertainties indirectly, the focus was on minimizing project completion time. This however did not help practioners to deal with real case problems. As a result, Time Planning under Uncertainty becomes the focus in Time Planning with four major considerations [Tigist, 2004]:

- uncertainties in detailing of activities,
- uncertainties in estimating activity durations,
- uncertainties in resources dependencies, and
- Uncertainties in activities or tasks dependencies related to merge event effects.

The first was addressed by detailing of activities successively using Successive Principles; and the second uses Stochastic Approach to estimation, Random Simulation of activity durations and Buffer Provisions using PERT, MCS and Theory of Constraints (TOC).

The third was related to RCPS and Resource Buffers provisions using TOC are used to cater for resource dependencies. The fourth was related to merging activities due to parallel or multi - tasking issues and are considered using Correction Factors computed to cater for the Merge Event Bias (MEB).

This paper reviewed four methods used for time planning under uncertainty. These are PERT, Monte Carlo Simulation (MCS), Successive Principle (SP) and Theory of Constraints (TOC). PERT was already covered before; therefore the following sections present the remaining three methods.

**Monte Carlo Simulation (MCS)**

Simulation is a concept used in time planning to provide insight into the range and distribution of project completion times [Mantel, et al, 2001]. MCS is a process that repeatedly sets values for each random variable by sampling their variable's respective distribution in order to compute the critical path, slack values, and their probability of completions [Klastorin, 2004]. This technique calculates sets of artificial but realistic activity durations and then applies a deterministic scheduling procedure to each set of durations. For realistic project networks, 40 to 1,000 separate sets of activity durations might be used in a single scheduling simulation.

It generally helps to determine multiple possible completion times of projects together with their percentages of criticality. Besides, a number of different indicators of the project schedule can be estimated from the results of a Monte Carlo Simulation:

- Estimates of the expected time and variance of the project completion.
- Estimate of the distribution of completion times, so that the probability of meeting a particular completion date can be used.
- Probability that a particular activity will lie on the critical path. This is of interest since the longest or critical path through the network may change as activity durations change.

**Successive Principles**

Successive principle is a recent development to support decisions for a reliable plan focused on managing uncertainty [Lichtenberg, 2000]. It is also found applicable to time and cost planning under uncertainties for construction projects [Klakegg, 1994; Austeng and Hugstad, 1995]. Lichtenberg presented its underlining philosophical logic into five major philosophical logics (Box 3).

Based on these philosophical logics, the successive principle has developed seven working procedures called 'the step-by-step process' (Figure 5). While the qualitative phase shared three of the first seven procedures largely, the quantitative phase is used in the remaining four procedures.

Box 2: The five underlying philosophical logic of successive principle

- Consider uncertainties as natural and exciting aspects of planning and management
- Use **Resources Group** to bring stochastic effects to planning
- Deal with Major or Root Influencing factors first
- Follow **Top - Down Approach** in detailing factors; and

However, use of Qualitative approaches in the Quantification process and its evaluation is unavoidable because resources group and brain-storming processes are applicable in all procedures.

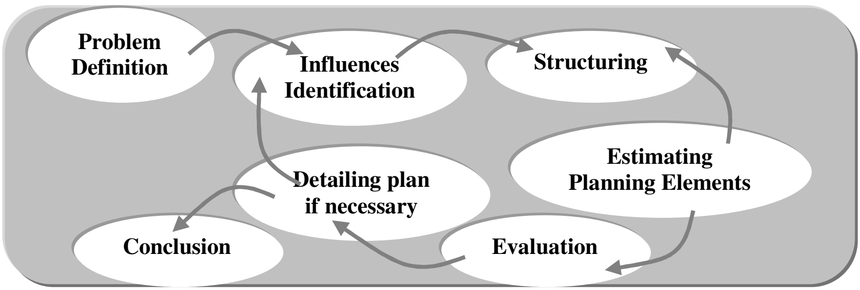
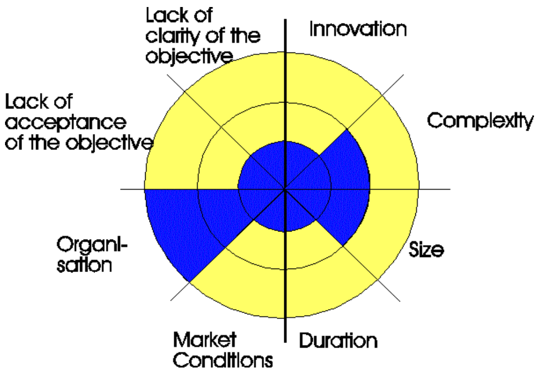



Figure 3: The Seven Step-by-Step Working Procedures of Successive Principle (Source:

Use of a Situation Map (Figure 6) was developed to help in clearly defining the problem for the resources group. A situation map is used to quantify and visualize the planning variables that serve as a reference for evaluating the outcomes of the planning process.




The second step is called '**identification of overall influencing factors**' and is used to identify both internal and external influencing factors called 'Major Factors or Root Uncertainties'.

In this step, the most important issues considered are:

- identifying uncertainties using brainstorming techniques;
- categorizing & formulating 'Major Factors or Root Uncertainties'; and
- defining benchmarking for major uncertainties.

These overall influences were meant to substitute the co-variances computed in Monte Carlo Simulation method. For general use, four categories of overall influence factors were identified. These are Political, Geographical, Product related and Organizational factors (figure 7). However, these factors can be re-categorized for specific conditions under which the projects are undertaken.

| | |
|---|---|
| **Political**<br>• **Policies**<br>• **regulations** | **Geographical**<br>• **Weather**<br>• **Location** |
| **Product related**<br>• **Type**<br>• **Size** | **Organizational**<br>• **Contracting**<br>• **Stakeholders** |

Figure 5: Overall Influencing Factors

The third step is well acknowledged as 'Work Break Down structures (WBS)' in Construction Management but in the case for successive principle their level is limited to major uncertainties to account for its very basic philosophical logic, that is; the Top Down approach to planning. Successive principle called this process 'Structuring'.

This approach is important because successive principle is systematically developed to reduce uncertainties and details them only when their consequences were proved vital for the planning effort. All these three steps as part of the Qualitative process rely most on the work of the Resources Group using brainstorming technique.

The remaining four steps are:

- forecasting uncertain parameters using stochastic estimating – Estimating planning elements;
- prioritizing the importance of the activities for the planning efforts - Evaluation;
- successively detailing (limited to 5 to 10 cycles) prioritized activities – Detailing if necessary; and
- establishing an action plan based on the uncertainty profile (usually the top ten lists) - Conclusion.

The first step in the quantitative phase (4th step in the working procedures) uses the so called 'group triple estimating technique'. In successive principle use of resources group put forward these triple estimates. The two extreme estimates are taken to be the 10% and 90% fractiles because it was difficult to estimate 1% and 99%

fractiles. Besides, the most likely value was taken as the median and fixes its fractile at 50%; not mode in the case for PERT method.

Successive principle uses Erlang distribution function (a part of γ distribution function) with k values of 10 to determine theese three important parameters; the mean value (μ), the standard deviation (σ) and its variance (Var). Accordingly, they are determined using their expressions (Eqns. 5 - 7) in Box 5.

Box 5: Expressions for stochastic parameters

$$\mu = (t_{mn} + 3{*}t_{ml} + t_{mv}) / 4.9 \quad \text{....... Eqn. 5}$$

$$\sigma = (t_{mx} - t_{mn}) / 4.6 \quad \text{........ Eqn. 6}$$

$$Var = \sigma^2 \quad \text{........ Eqn. 7}$$

Where: $t_{mn}$ = the minimum extreme value (10%)
$t_{ml}$ = the most likely time value (50%)
$t_{mx}$ = the maximum extreme value (90%)

The fifth step called 'Evaluation' uses three concepts with regard to time planning; namely, Critical Indices (CI), Merge Event Bias (MEB) and Priority figures (P). Critical Indices: The CI shows the degree of a probability that an activity or a path can be critical when compared to other activities and it ranges between 0 to 100%. Lichtenberg [2000] suggested that 100, 80, 20 and 0 % CI values stands for Clearly Critical, Near Critical, Less Critical and Clearly Non - Critical activities respectively.

**CIs** are computed using backward pass computations such that the End activity receives 100% CI if it is a single activity. Those activities possessing sufficient floats implying no condition for them to be critical receives 0% CIs. Following the backward bass computations the CIs can be computed using the following criteria:

- n parallel activities with equal uncertainty shares equal CIs obtained for that path sharing these parallel activities. If these parallel activities are the only path within the network, their CIs = 100 / n.

- n parallel activities with unequal uncertainty can be determined using graphical expression given in Klakegg **[1994]** and similarly, the parallel paths share the CIs obtained using the Backward Pass Computations.

Merge Event Bias (MEB) is essentially due to uncertainties related to carrying out parallel tasks or multitasking, their activity duration estimates and their 'and logic' within the network. For instance, let us consider two activities A and B which are merging to the same node leading to activity C; traditionally (using PERT & CPM) activity C is assumed to start at the maximum finishing time of Activities A & B.

However, the uncertainty involved in estimating the activities durations together with their 'and logic' implied the use of expected values computed from the product of the estimated activity durations and their probability of completion. As a result, the Starting time of Activity C can be influenced by the number of parallel tasks with in a merging path. MEB is then considered using Møllers method where correction factor is computed based on the concept of near and far splitting activities [Klakegg, 1994]. The Priority figure, P is computed as the product of the CIs and the Variance of the activities under consideration.

The sixth and seventh steps are there either to cause iterations if there are uncertainties which require detailing and go back to step 2 or conclude by establishing an action plan for time planning.

**Theory of Constraints (TOC)**

Theory of Constraints is a recent management philosophy based on two major conceptual developments [Goldratt, 1997; Newbold, 1998; www.eas.asu.edu, 2003]; namely, use of chain analogy; and continuous improvement approach [Dettemer, 1997 - Box 7]. TOC can also be applicable to Project Management and Time Planning under uncertainty [Klastorin, 2004; Mantel, et al, 2001].

Box 7: The two major conceptual guidelines

1. **Chain Analogy:** System thinking is preferable than Analytical thinking in managing changes, uncertainties and solving problems.
   a. System can be analogous to Chains and it has a 'weakest link (a constraint)' that functions as an ultimate limiting factor to the overall objective.
   b. Few constraints manifest through a number of undesirable effects linked by network of cause and effect relationships. Therefore, the System Optimum is not the Sum of the Local Optima but the optimum functioning of the Weakest Links step by step.
   c. Core Problems embody hidden and underlying conflict requiring their resolution through challenging their assumptions built behind.
   d. Knowing what to change (the few constraints) requires a thorough understanding of the Current Reality, its Objective (the desired future), and the magnitude and direction of the difference between the two.
   e. Policy constraints are more difficult to identify and challenge than physical constraints.
2. **Continuous Improvement:** Today's problem is the result of Yesterday's solution, i.e.; optimum solution deteriorates over time; hence ongoing improvement is a requirement.
   a. Inertia resists changes which tends to keep the stats quo and serves as a block

The Chain Analogy claims that systems behave more like chains or networks of chains built upon interdependent activities. Furthermore, it argues that there is only one core problem at a time (Figure 5), and make the theory to emphasize on finding and supporting this main limiting factor called the system constraint or the weakest link in order to improve the system as a whole.

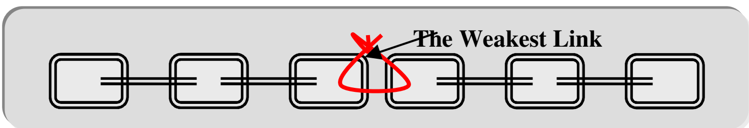



Figure 5: The Critical Chain and Its Weakest Link (Source: Dettemer [16]; pp. 8 & 10)

This Constraint could be the absence of any requirement such as an individual, equipment, a material, etc. Subsequently its fundamental belief is built upon strengthening this weakest link using two main features: Resources Dependencies and using Buffer Management. These features in combinations are the main characteristics that differentiate critical chain from the traditional critical path approach.

While Critical Path is a path which can be determined by comparing with other paths in a network where multitasking can have an effect in changing it during implementations; Critical Chain is the only path that characterize time planning where non critical activities joins it in the form of tree branches with appropriate buffers provided. That is; Critical Chain does not change as in the case for a Critical Path.

TOC first uses the concept of Critical Path to show task dependencies and further considered resource dependencies to identify what it called the 'Critical Chain' and the Work in Process (WIP) using activities late start times [Helleron and Leus, 2001]. These activities are moved to their early times when they are confronted with resource constraints to resolve resource dependencies [Newbold, 1998; www.eas.asu.edu, 2003]. This approach helps to avoid multitasking because resources available and required are made balanced. The Critical Chain can then be determined using three steps:

1. Create the initial network using CPM;
2. Load leveling using Resources dependency; and
3. Determining the Critical chain.

While the first step is targeted to minimize WIP using late start times; the second step is for load leveling to resolve resource conflicts.

Finally, the critical chain is identified using the above two concepts which estimates the overall duration of the project focusing on both WIPs and their Resource conflicts. TOC then considers uncertainties of deterministic estimating by providing three different types of buffers; namely Project, Feeding and Resource Buffers as contingencies or safety times.

The Continuous Improvement Approach is meant to address three major questions [Goldratt, 1997; www.eas.asu.edu, 2003; wikipedia, 2003; tarkan, 2003] in order to deal with changes and uncertainties within projects. They are: What to change? What to change to? and How to change? It uses 'Five Thinking Processes' otherwise called 'Five Logical Tools' [Dettemer, 1997; www.eas.asu.edu, 2003; tarkan, 2003] and 'Five Iterative or Focusing Steps' [Goldratt, 1997; Newbold, 1998; www.eas.asu.edu, 2003; wikipedia, 2003; tarkan, 2003] as an integrative package to deal with these three questions (Figure 7).

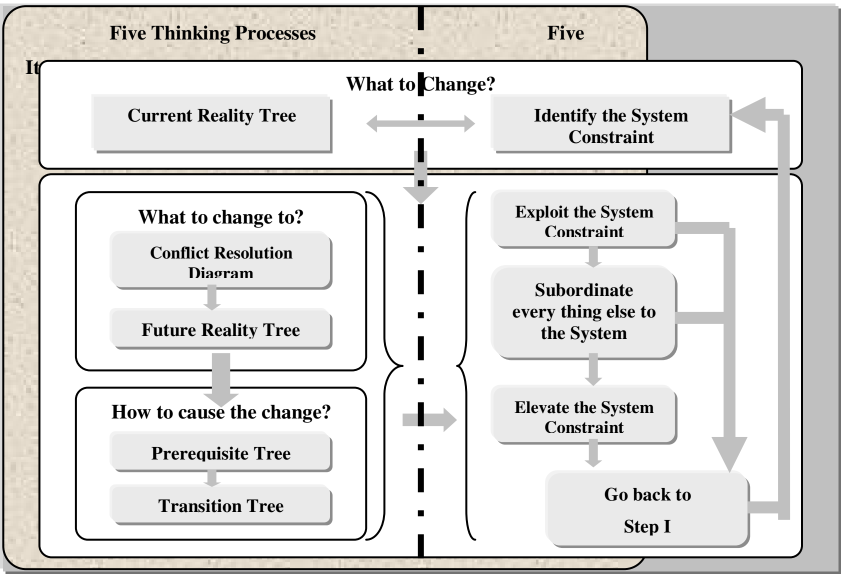



Figure 7: The TOC Continuous Improvement Approach

TOC's first focusing step is to identify the system constraint(s). The Current Reality Tree (CRT) helps in identifying the constraint(s). In time planning, CRT is used to identify potential constraints or uncertainties causing delays in completion. The CRT uses Undesirable Effects or Symptoms as a source of information to work back and identify major problems called Constraint(s).

This step is augmented by its following step which makes preferences **to subordinate everything else** for enabling the constraints to achieve its maximum effectiveness. It is only after this that the constraints were analyzed to seek for its inability to improve the whole net-chain.

In order to carry out this task, TOC assumed that knowing what to change requires a thorough understanding of the system's current reality and its constraints. The Conflict Resolution Diagram (CRD) is a tool used to identify what to change by solving potential conflicts such as resources and task dependencies among the constraints.

TOC is then uses Future Reality Tree (FRT) to deal with 'What to change to?' The FRT starts with the proposed outcome called Desirable Effects to work back and identify possible alternatives at different levels to improve the current reality which is similar to time crashing techniques.

The fourth focusing TOC step is required if and only if the constraints could not be improved within the other two steps preceding it. TOC called this step as '**to elevate the system constraint(s)**'. It is at this step that the question 'how to change?' is addressed.

TOC uses Prerequisite Tree (PRT) and Transition Tree (TST) that can forecast the obstacles likely to occur and overcome such obstacles. The PRT similar to the FRT starts with the objective to work back and identify possible intermediate objectives to attend to. The TST also starts with its objective followed by identifying the improved current reality, need and specific action to produce the subsequent effects one after the other.

The fifth focusing TOC step can be called upon to iteratively improve the constraint(s) one by one. This step leads to go back to the first step to identify the next constraint. These five thinking processes together with the five focusing steps are useful in determining uncertainties during time planning.

Buffer Management: Newbold [1998] described the use of Buffers to protect project completion by allocating safety times to key areas of the schedule. When compared to the project tracking approach, TOC allows safety time to assess the impact of uncertainties whether the project required significant corrective actions or not.

This comparison can be diagrammatically shown in figure 8. Figure 8 showed that use of Buffer management minimizes frequent scheduling because it uses the three safety times strategically positioned first to exploit all possible capabilities and also subordinate all other non-critical chain activities to maximize the opportunity of the weakest link. This is shown by its iterative treatment before re-scheduling is carried out. The re-scheduling measure can only be done after assessing the option of elevating the project constraint.

Rand **[2000]** noted that project overrun is related to the misuse of safety time created within the estimated times for each activity. That is, the use of three estimates and their weighed mean is a consequence of planner's perception to overestimate times to provide a reasonable degree of certainty for their completion. This is because they believe that the uncertainty existing is the underlying main cause behind delays in completion, and hence adding safety to their planning is a better approach.

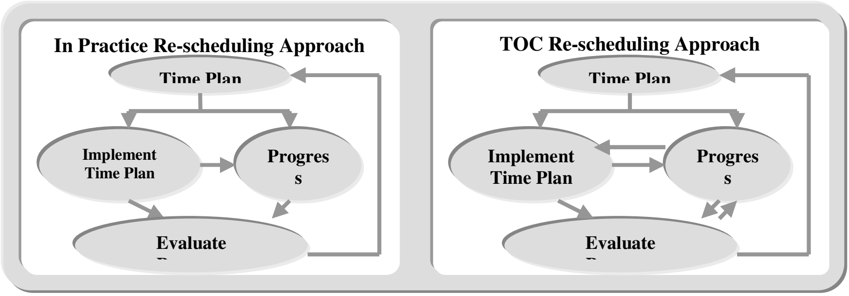



Figure 8: Tracking versus TOC approach to Re-Scheduling

Therefore, it is not only the uncertainty that matters most in time planning; but also the way how these uncertainties are managed. TOC has then argued that if safety time is included to each estimate, then;

**1st. Parkinson's Law**

Starting time will be delayed due to the perceptions built on workers which verify Parkinson's Law; that is, work expands to fill the time available. As a result, reluctance to complete activities at their earliest completion time is exhibited or their starting time is delayed what was called 'Students Syndrome' - leaving everything to the last minute.

Therefore, TOC uses deterministic time estimate similar to CPM model and avoid wasting slack time to encourage early task completion. Besides, safety times are added in strategic positions along the critical chain to tackle uncertainty. TOC called such strategic uses of safety times Buffer Management. This part of the problem is dealt with the Project Buffer (PB) which is placed at the end of the project.

This will help to reduce the perception of workers to postpone starting times or Parkinson's Law attitudes. Besides, Project Buffer protects commitment dates from fluctuations on the critical chain. This approach tallies with exploiting all possibilities to complete on time before elevating for uncertainties by allowing safety time to each activity using triple estimates.

On deciding the buffer size, Newbold [1998] acknowledged that they cannot be precisely determined. This is because statistical fluctuations exist and by definition they can only be estimated. He suggested that the Project buffer shall provide at least 90% chance for completing the project on time.

Newbold then suggested 50% of the unpadded critical chain duration can be assumed for the project buffer. It is also possible to use mathematical or simulation models alternatively using the following expression (Eq. 9) to estimate the buffer size (the buffer size is assumed to be twice the Standard Deviation). Eqn. 9 is based on the Central Limit Theorem that stated the sum of distributions will resume to be normally distributed.

$$\text{Buffer} = 2\sigma = \sqrt{\Sigma\,(t^{p}_{i} - t^{m}_{i})^{2}},\ i=\{1,2,3,\ldots.n\} \quad \text{(Eqn. 9)}$$

Where; $\sigma$ = the standard deviation;

$t^{p}_{i}$ = the pessimistic or worst case estimate of the tasks on the critical chain;

$t^{m}_{i}$ = the mean duration (median as per Goldratt) of the tasks on the critical chain; &

$n$ = the number of tasks in the critical chain.

**2nd. Multi-tasking and the effect of late start undermined the start of the following activities.**

That is, if the completion of the previous activity is unclear because it is likely to delay, then the preparation for subsequent activities is not done. This increased the probability of late start for subsequent activities which will further delay and cause time overrun on the completion time. This will be more influential when there are near critical activities joining the critical path.

TOC tackles such problems by choosing strategic positions where non-critical activities join the Critical Chain and providing what it called 'Feeding Buffers'. Feeding buffers are used to protect the critical chain from delay of feeding tasks by providing safety times [Klastorin, 2004] based on the principle called subordinating everything else to the critical chain. Newbold **[1998]** suggested similar buffer size but only for the path leading to the feeding buffer.

**3rd. Resource dependencies also were recognized as uncertain due to resource constraints.**

Projects are well known for their use of borrowed resources such as labor and equipments and the fact that line managers are largely responsible for resource allocations, the case of resource constraints is not doubtful.

TOC in dealing with such uncertainties, employ **Resource buffers** that protect the critical chain from lack of availability of required resources and provides the possibility for critical chain tasks to start early. Resource buffers are deployed wherever a non- critical chain task or blank space joins the critical chain by looking the resources view. Newbold called such resource buffers as '**weak up calls**' to make sure critical chain tasks will not be starved for resources. He suggested that two weeks long resource buffer sizes are often sufficient.

## Conclusion

This paper reviewed the four conceptual developments of Time Planning with considerable focus on today's problem such that practitioners in the construction industry could use them for time planning under uncertainty.

PERT, MCS, Successive Principles and Theory of Constraints were identified together with issues related to task and resources dependencies in order to forecast and plan time usage in construction projects. The concepts of chain analogy, continuous improvements, buffer management and the use of resources group was indicated to enhance the forecast accuracies in time planning under uncertainty.

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