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IMPLICATION OF THEORY OF CONSTRAINTS IN PROJECT MANAGEMENT

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Abstract:

Theory of Constraints (TOC) is new concept of project management. It has been effectively used in the manufacture industry. This study explores the idea of how the TOC is applicable to improve the project performance dealing with time constraint with a case of Sankosh-Tipling Road project and Bhimdhunga-Lamidanda Road Project of Dhading District. The five basic steps of TOC to remove the constraints are identifying the constraint, exploiting the constraint, subordinating to exploitation, elevating the system performance and repeating process. Critical Chain Project Management (CCPM) approach has considered the human behavior factors like Parkinson's Law and student syndrome while rescheduling the project. Buffer management was introduced with considering the human behavior factors for manipulating the activity duration to aggressive time estimates. Buffer Management uses the time buffers viz. Project Buffer and Feeding Buffers as well as Resource Buffers. These buffers signal the warning of its consumption as the activities are implemented and suggests to critical look at the processes without exceeding the project duration. It was assessed that project could be completed 30 weeks prior to originally proposed deadline with application of CCPM. It might not be very ideal condition and could not be completed 30 weeks prior to deadline but CCPM ensures the project completion within originally proposed deadline with effective management of buffers. Thus, this study has assumed that project could be completed within previously proposed deadline if different counter measures which have been suggested with consideration of TOC.

Key Words: Rural Road Projects, Buffers, Parkinson's Law & Critical Chain

Introduction:

Project Management objectives are the successful development of the project's procedures of initiation, planning, execution, regulation and closure as well as the guidance of the project team's operation towards achieving all the agreed upon goals within set scope, time, quality and budget standard(Oberlender, 1993). The purpose of the project management is to foresee or predict as many dangers and problem as possible; and to plan, organize and control activities so that the project is completed as successfully as possible in spite of all the risks. The ever-present element of risk and uncertainty means that events and tasks leading to completion can never be foretold with absolute accuracy.

However, many constraints exist in practice with regard to construction project resulting the failure of projects. There are numerous challenges facing today's Construction Manager (CM) due to direct and indirect peripheral activities in construction processes. A surprising number of challenges are not construction issues but must be addressed and managed by the construction manager to ensure project success. Some of the construction issues include workforce considerations, time constraints, resource constraints, quality constraints and the changing nature of the work. These constraints are the most limiting factors that has restricted the overall project performance for timely completion of projects. Non-construction challenges that CM face that are part of business landscape include legal issues, governmental regulations, environmental concerns, and socio-political process. Most of the road construction projects in Nepal, both completed and ongoing are suffering badly from time and cost overrun and its consequences. Some of them have time overrun for short duration while some have time overrun for many years causing loss of project's profit, increasing cost and leading to technical and managerial problems between project's parties (Shah, et al., 2017). Thus, delay as a time constraint due to consequences of several other constraints, has a frightening economic problem, which not only wastes financial resources but also reduces the pace of development activities. To overcome such delay and overrun, effective project management with planning, scheduling and controlling is necessary. For effective planning, scheduling and control, the identification of constraints in the system is very necessary. The identification of the constraint in early stage of the project assist to make the organizational decision. The traditional scheduling approaches have been extensively applied in construction to identify the necessary activities and determine activity start and finish times. The basic approach has the problem in the ability of dealing with non-precedence constraints, human behavior factors, although traditional approach is simple to use and solve sophisticated problems.

It is fact that constraints should be managed effectively in view of construction schedule planning and control. Most available methodologies to solve the non-precedence constraints include hit and trial approach, optimal solutions and simulation approach. Another solution for solving the problem regarding construction constraints is use of Theory of Constraint (TOC). TOC has been widely used and accepted in the manufacture industry to improve the production performance but its application is yet to be tested in construction sector, especially in context of Nepal. TOC suggests five focusing steps to identify the major constraint in the system and to remove until it is no longer constraint. An approach regarding TOC which is Critical Chain Project Management (CCPM), is very effective to remove the time constraints with buffer management. Buffer management includes the time buffers manipulating the activity time estimates considering the human behavior factors.

The reason behind the study was to deal with the project constraints which can restrict the project performance. This study has applied the theory of constraints considering the major constraints to ascertain the timely completion of construction projects. This study's significance is for optimizing the project performance by identifying and removing the constraint. This study also has used a Critical Chain Project Management (CCPM) tool to manage and reduce time constraints. So, significance of this study is a basic guide to any construction project manager for applying Theory of Constraint (TOC) to improve the performance of the project. This is a case study considering the rural road project, so, this will be an approach assisting to Engineers and Construction manager for successful implementation of project dealing with constraints. Though, TOC is new in Nepalese context, literature availability is very rare, this study results will be fruitful literature to future researchers or students willing to research in discipline of TOC. Critical Chain Project Management approach is very important in project management. With help of this study, it will be easy to understand how the time buffers and resource buffers can be used for effective scheduling of the projects encapsulating human factors on activity time estimate. This study also helps in usingTOC tools for monitoring and controlling of construction projects. Indeed, significance of this study is to introduce the TOC approach and Critical CCPM in road construction. Literature has shown TOC is highly applicable in industry due to their repetitive nature of work where constraints were easily identified, this study has tried to implement TOC where projects are unique in nature and identifying and managing constraints are challenges for practitioner. This study will be effective to elaborate the scope of TOC in case of rural road construction as well as other construction project management in context of Nepal.

Research Objectives:

The overall objective of this study was to apply the Theory of Constraint (TOC) and Critical Chain concepts in road construction project to improve overall performance for effective scheduling.

Problems with Traditional Project Management:

When planning for an upcoming project, estimates for task durations are required. In order for the plan to be realistic, much time is spent ensuring estimates are accurate. Accurate estimates give us increased probability and high confidence in the task completing on time. Thus, allows an additional safety time beyond the work context time required to be embedded within task duration. The more safety in a task the more there is a tendency to behave in the following ways.

Bad Multitasking:

The process of stopping the work before it is completed, in order to do other work that is perceived as more urgent or important, each time the task execution is stopped; there is immediate loss of efficiency because of the need to remember details in order to resume the task execution later (Kevin, 2007). Difficult mental tasks may require considerable time to return. Even worse, one task's execution stop delays the consequent tasks execution as well. As a result, the overall duration of the project increases. Most companies are willing to admit that a bad multitasking takes place and that people tend to have a lot of simultaneously opened tasks this quickly leads to the "cascade effects". In other words, the delay spreads like a domino effect in the project, increasing the overall duration and delaying the project. The second and third factors are directly related to how companies manage spare time in their projects.

Student Syndrome:

While this makes sense, and this is done with the best intentions, the effect on the project is devastating. As soon as the safety margin incorporates into the assessment of the time the student syndrome arises. First, students request additional time to prepare for the test and when they get it, seems that there is a lot of time and urgency removed, they are not being prepared for the test until the next deadline approaches. Same thing in projects, when people are busy, and estimate that the amount of time to execute the task is enough, they will not have a real reason to get started. As a result, most of the safe time included in each task is wasted at the beginning of the execution. Student syndrome contributes significantly to the increase in time delays of the projects (Woeppel, 2009). It pledged that the safe time is not actually used to perform the wok, despite the best intentions of the people. And very often the following situation arises: safety time that was consumed by the "students" in the beginning, becomes necessary in the end to overcome some unexpected obstacles. But it is not existing any more. As a result, the task is delayed, even though that it was enough time and safety margin to finish it on schedule.

Parkinson's Law:

On the other hand, each task is affected by Parkinson's Law. It ensures that, if the safe time has been added and has not been used up, the task would not be completed before the scheduled time, even if there are not any obstacles. In fact, there are two pitfalls. Firstly, when people have more time to complete the tasks, they often use that time to "improve" of "polish" it. So that work expands to fill all available time Secondly, to finish work early - a disincentive for people, finishing the task long before the deadline indicates the administration that the assessment of the timing was too "fat", and that in fact it can be done much faster (Woeppel, 2009). The next time limit of a task will be reduced to reduce the overall project duration. Taking this into account, workers would not ever finish their tasks earlier than expected to keep their safe time untouched.

The traditional tools used to manage projects: Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Gantt Chart etc do not address the misuse of embedded safety and consequently behaviors they have. The basic CPM/PERT approaches do not deal with the hidden constraints. Dr. Goldratt proposed the Theory of Constraints (TOC) and Critical Chain, which provide the concepts for achieving effective removal of these constraints.

Buffer Management:

There are three kinds of uncertainties in project planning and scheduling namely "activity time uncertainty", "Path time uncertainty", and resource uncertainties, in order to reduce those uncertainties, buffers are utilized and applied in Critical Chain Project Management (CCPM) (Vanhoucke, 2012). In the Critical Chain, buffers are added durations and applied to a project schedule to protect what is important to the success of the project. The buffers using in the critical chain include project buffer, feeding buffer, and resource buffer. The function of project buffer is to protect the promised due date from variation in critical chain. The function of feeding buffers is to protect the critical chain to maintain its relay race performance by buffering the activities in non-critical chains and critical chains where they merge with activities in critical chain(Leach 2004). With a properly feeding buffer duration inserted, the activity in critical chain that relies inputs from that non-critical chain has an improved chance of being able to start as soon as its predecessor activity in critical chain is complete. The function of resource buffer is an information signal to resource planned to work on the project critical chain that the project task is coming up for work. Resource buffers are unlike the other buffers, as they do not directly influence the scheduling of the project.

Buffer management approach of project scheduling has following six steps in project management (Vanhoucke, 2012).

- Step 1: Come up with aggressive estimates
- Step 2: Construct an As Late As Possible (ALAP) schedule
- Step 3: Identify the Critical Chain
- Step 4: Determine appropriate buffer positions
- Step 5: Determine appropriate buffer sizes
- Step 6: Insert buffers into the schedule

Step 1: Come up with aggressive estimates

Based on the general idea that the protection of the project deadline is the primary goal rather than the protection of each individual project activity, the activity durations should be set to an aggressive estimate to avoid that the work of an activity is smoothed out over a longer duration than really necessary. Goldratt mentions three main reasons why project activity durations often are smoothed out over longer durations as follows:

- Murphy's Law: If something can go wrong, it will.
- Student Syndrome: Wait till urgency.
- Parkinson's Law: Work expands to fill the allotted time

Aggressive time estimates refer to time estimates where the probability of exceedence is relatively large eg. The 50% percentile.

Step 2: Construct an ALAP schedule

In contrast to the commonly used earliest start scheduling approach mostly used in traditional management and scheduling, it is suggested to schedule each project activity as-late-as possible nearby its predefined project deadline. The latest start schedule is quite risky since it makes every project activity part of the critical path which might put, in combination with the aggressive activity time estimates.

Step 3: Identify the Critical Chain

Similar to Critical Path concept that distinguishes between critical and non-critical activities, a resource feasible project schedule has a so called critical chain defined as the longest chain in the project determines the total project duration. The main difference with the critical path concept is that it takes the limited availability of renewable resources into account.

Step 4: Determine appropriate buffer position

The new idea of the buffer management techniques in the clever positioning of buffers is to protect the project deadline through the use of three types of buffers. Each buffer has a specific goal and needs to be positioned at the right place to protect the right part of the project data as follows.

- Project buffer: A unique and single buffer to protect the project deadline.
- Feeding buffer: Multiple buffers to protect parts of the critical chain.

- Resource buffer: Multiple artificial buffers that act as warning signal to assure the availability of resources.

Step 5: Determine appropriate buffer sizes

Sizing buffers as a way to put safety time in the project is a crucial step of the buffer management approach. Both the project and all the feeding buffers need to be sized appropriately to be able to act as buffers against delay. Although Goldratt initially proposed to use simple 50% rule i.e. the size of buffers is equal to 50% of the duration of the project activities it should protect, a cleverer way should be used that size buffers according to the risk of the activities it should protect.

Step 6: Insert buffers into the schedule

Inserting buffers into the project schedule creates a buffered project baseline schedule that acts as a tool to measure performance and provides dashboards (i.e. the buffers) that need to be monitored to trigger corrective actions.

Buffer Management in Construction:

In order to manage uncertainty in construction projects, buffer management is utilized to make assessment of the consumption and replenishment of buffers regard to activities and project. Buffer management may provide a clear view of the cumulative risk impact to the project performance (Steyn, 2001). Compare with CPM approach, Critical Chain includes the consideration about resource constraint and focus on cause uncertainty management. The following is the brief illustration to the application of Critical Chain Project Management (CCPM) in construction. As same as the previous description, three estimated buffers are integrated with CPM approach. All procedures are shown in figure 2.4. The project buffer is placed at the end of the project after the last critical chain activity to protect schedule against overruns. The feeding buffer is placed at the intersection between non-critical and critical chain to protect the Critical Chain against overruns on these feeding chains. Resource buffer is placed at the critical chain to ensure that resource is available when needed to protect the critical chain schedule. Resource buffer helps insurance of resource availability and does not add time to the critical chain.

In CCPM, Goldratt proposed that when making plan and schedule, the planner assumes that each activity may complete his works at the mean time without impact of uncertainty. All the safety times in activities should be removed unnecessary wasting time. Furthermore; Goldratt suggest the size of buffer is 50-50 estimated durations. However, the 50% estimation is too arbitrary and difficult to apply in construction schedule plan. In order to improve the above problem, a modified approach is proposed to estate buffer more reliable. In construction, the duration estimation of each activity is usually estimated based on planner experience or calculated by average work production rate. However, the estimation usually is longer than the average time because planners always add safety time into activity for any uncertainty. Usually, most of work estimates cannot make sure 100% effort on the activity. If the activity estimation is not 100% effort or people work in the lax attitude, activity duration will be reduced and remove the safety time. In order to solve above problems, the two questions will be used and asked for each activity from participating engineers. First question is “how long you could perform this activity based on your previous experience?”, another question is “how quickly you could perform this activity if everything goes thorough well and you had all the inputs you needed at the start?”. After getting the initial “protective” estimates from first question and obtain “reasonable” estimates according to question two. However, the engineers need to explain the reasons if the protective and reasonable estimation are based on question one and two. After obtain the protective and reasonable estimates, the chief engineer may judge and determine the final estimating duration for each activity. Therefore, the safety time of each activity is protective estimation minus reasonable estimation. When buffer is increasing, it means that project may be finished ahead of schedule. On the contrary, it implies that the project will be possible to delay if buffer is decreasing. The following is the main process applying buffers in construction projects (Jan& Ho, 2006).

Step 1: Plan the Construction schedule using CPM approach.
Step 2: Identify and determine the protective estimation for each activity.
Step 3: Identify and determine the reasonable estimation for each activity.
Step 4: Remove the safety estimation for each activity based on step2 and step3.
Step 5: Identify the critical chain as the longest chain of dependent events for the feasible schedule that was identified in step4.
Step 6: Add the project buffer to the end of the critical chain.
Step 7: Add the feeding buffers in a non-critical chain merging into critical chain.
Step 8: Add the resource buffers to ensure the activity to resource availability.
Step 9: Return the step5 to check critical chain.

Buffers can be utilized effectively in construction project for planning and controlling. In traditional project management, the critical path changes as activities are completed ahead or fall behind schedule. With buffer management approach, buffers prevent the critical chain from changing during project execution. Briefly, the Critical Chain Project Management (CCPM) provides a rigorous plan and simplifies project control and utilizes buffers reducing the risk of a delay in construction.

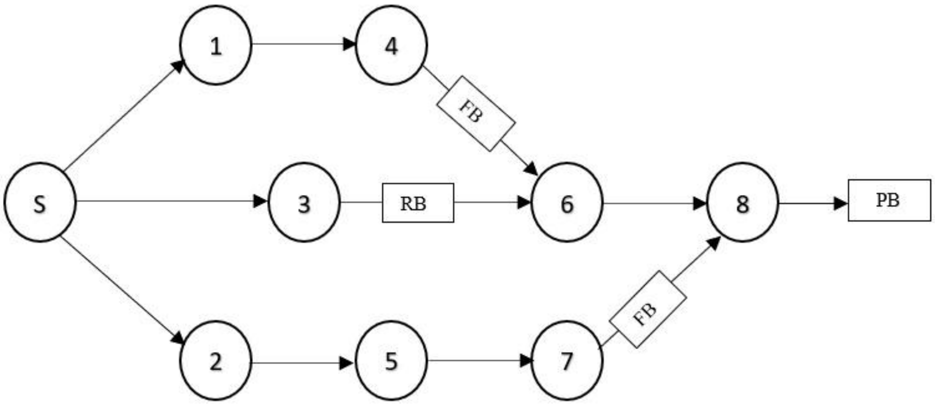

Figure 1: Application of Buffer in Critical Chain

Critical Chain: S-3-6-8
FB: Feeding Buffer, PB: Project Buffer
Source: (Vanhoucke, 2012).

Project Buffer:

A single Project Buffer (PB) is added at the end of the project Network between the last activity and the project deadline and PB is the sum of removed safety time of the individual activities lying on critical chain (Vanhoucke, 2012). Any delays on the critical chain will partly consume this buffer without having an effect on the project completion date. Consequently, a project buffer acts as a protection of the project completion date which might be variable due to changes in activity durations on the critical chain. Its size should depend on the expected changes and variability of the activities on critical chain.

Feeding Buffers:

Any path of activities merging into the Critical Chain is called a feeding chain. Buffer inserted at the end of feeding chain before critical chain is the Feeding Buffer (FB) and which is sum of the removed safety time of the individual activities lying on feeding chain(Vanhoucke, 2012). Since the project buffer is inserted in the project schedule as a protection of project deadline against changes in the critical chain, the critical chain should also be protected against changes in feeding chain, so that, feeding buffers are inserted in between feeding chain and critical chain.

Resource Buffers:

While both the project buffer and feeding buffers act as mechanism to transpose the removed safety time of the individual activities to safety buffers, resource buffers act as warning signals that ensure the timely availability of project resources (Vanhoucke, 2012). More precisely, resource buffers can be set alongside of the critical chain to ensure that the renewable resources are available to work on the critical chain activities as soon as they needed.

Methodology:

Sampling and Population:

Study was conducted based on purposive sampling method with 100% of targeted sampling i.e. Project Implementation Members 21 persons.

Collection of Data and Information:

The stakeholders of the project were Donors, GoN, Contractors, Consultants, Building Groups, Beneficiaries, local people and etc. Both qualitative and quantitative data were collected and used in the study. Similarly, both primary and secondary types of data were collected and used in the study. Information / Data obtained from respondents were analyzed with the help of simple statistical tools and techniques. The collected and analyzed data have been presented in simple forms using charts, graphs and tables.

Primary Data:

The main techniques of primary data collection are:

a. Field Visit & Observation: The road project (study area) was visited. The work activities, its nature, it's complexity, work force, speed of work, geographical condition, location, social issues were observed. Informal meetings were conducted with stakeholders at site. Photographs of the site were also collected.

b. Questionnaire Survey: A simple set of questionnaires was also supplied to collect list of possible constraints in the project, causes and factor for the time and resource constraints, reliability of TOC variables. Interview/Questionnaire was also focused on the problems on traditional approach for scheduling of project. Questionnaire regarding status of projects, possible constraining factors, major work processes, availability of resources, scheduling technique, governing factors for time overrun and perception on student syndrome, Parkinson's law, multitasking was asked to the project team members (21 Nos) and also interview was conducted to know the perception on construction project management.

c. Desk Studies: Desk study was conducted to collect stakeholder's perception, understanding and view regarding the project management aspects of the road project. Desk study was carried out by close consultation with district project team consultant and client to understand the work flow methodology, characteristics of work, location, socio-political & Environmental situation of the work.

d. Case Studies: Case study regarding work schedule was carefully examined and analyzed by collecting the progress reports, documents, interim payment certificates, time extension documents, legal decision documents. Two different cases as shown in figure 3.1 were examined for the study, one for Sankosh-Tipling Road and another for Bhimdhunga-Lamidanda Road. For Sankosh-Tipling, work schedule submitted by contractor was examined for its analysis and generalized for network diagrams to fit within the Critical Chain Project Management (CCPM) approach and compared with the actual progress status. Then, CCPM with buffer managements were applied to overcome the time constraint. The basic five steps of TOC were considered for CCPM application by identifying the constraints through interview, questionnaire and content analysis, exploitation through buffer sizing and its placement, subordination through movement of non-constraint resources toward the critical chain activities and elevating the system constraints through addition of extra resources required in the critical activities. The time buffers which are project buffer and feeding buffers, were created by summing up of half of each activity duration from feeding and critical chain. Project buffer and feeding buffers were inserted at end of critical chain and feeding chains respectively. Then, Buffer penetration scenario was interpreted to know how the buffers are consumed as the activities are implemented and resulted the views regarding the project completion period whether it could be completed earlier as much as project buffer's size or within the pre-specified date of completion. For Bhimdhunga-Lamidanda, Project, constraints were identified through the questionnaire, key informant interview and content analysis, and basic steps of TOC were applied suggesting the counter measures with exploitation of resources, subordination of resources and elevating the system performance. Counter measures to overcome the constraint identified was supposed that it could ensure for completion of project within intended date of completion. These cases were discussed in-depth information regarding the construction constraints, effective schedule and planning, monitoring and control of project for timely completion of the project.

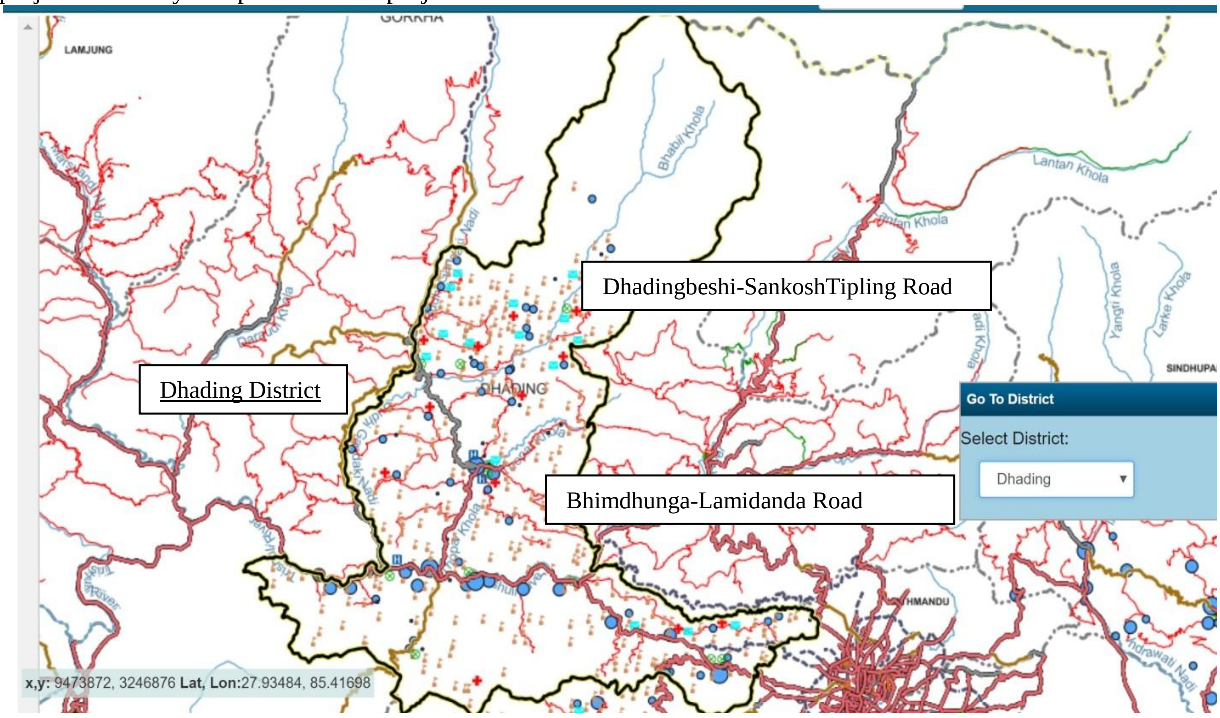

Figure 2: Location Map and Alignment of Roads

Secondary Data:

The secondary data were collected from the following Sources:

- Literature Review
- Documents and Reports of SNRTP program unit and DTOs.
- Publications of various Project management related researchers.
- Other published and unpublished literature, reports and journals.
- Internet and websites.
- Research Books.

Processing of Data:

In order to identify the major constraint in the proposed schedule in the case project, this study analyses the detail progress chart of the project and constraints which are impeding the progress of the activities. For this analysis, collection of the proposed scheduled bar chart, progress reports, interim payment certificates were collected. As well as, the field visit, interview and discussion were made with the consultants, the contractors and the employers and their representatives.

Content Analysis:

Contents of project reports were taken for analyzing the project progresses and overall status of the project. Bar-chart submitted by contractor were collected and analyzed whether it could fit or not within Critical Chain Project Management (CCPM). Performance variables like timeline, work progress, expenditure documents were collected and interpreted in tabular form as well as in S-curve diagram to understand the status of the project. Extension of project, variable for project time extension were also considered for understanding the delay of project. Last date of study was considered based on the last date of latest interim payment released to the contractor. Internal organizational strength like resource capacity, alternative solutions, future capacity requirements were discussed and analyzed for removing the time constraint.

Processing and Utilization of Data:

All the relevant data were processed and analyzed to determine the constraints in project, constraint in the scheduling, to determine the critical chain in the work schedule submitted, and to apply the TOC and CCPM approach to effective scheduling of project. After collection of necessary data, opinion and information of the selected respondents, the data and information were complied, analyzed and interpreted by the network diagram, S-curve and bar chart of schedule with management of time and resources.

Reporting and Presentation:

The interpretation of the proposed scheduling was presented in the form of bar chart and network diagram, S-curve chart, effective scheduling of the construction project using CCPM approach were also presented in the form of network diagram with buffer management of time and resources, as well as, the practical interpretation regarding monitoring and controlling of project schedule were shown in figure. Different counter measures were suggested based on TOC to remove systematically the time constraint with help of internal resources as well as the external resources. The work activities of the work schedule and optimized time schedule were carefully accessed, analyzed and interpreted for further study of the CCPM not only in context of the rural road construction but also for overall construction project management in Nepal.

Results and Discussions:

Application of Theory of Constraint:

Sankosh-Tipling Road Project:

For this project, the Critical Chain Project Management (CCPM) tool based on Theory of Constraint (TOC) was applied for removing the constraints identified.

Possibility of Applying Critical Chain Project Management (CCPM):

For this analysis, survey questions regarding human behavior factors were asked to 21 project implementation members from District Unit, Project Management Unit (PMU), and Central Project Coordination Unit (CPCU) for reliability and validity of the Theory of Constraint (TOC) variables regarding human factor in case of construction project. The human factors student syndrome, Parkinson's Law existence in working culture and Multitasking environment creating resource conflict and reducing project performance, were the objective of these questions.

Table 1: Student syndrome" existence in working environment

Total	Strongly Agree	Agree	Disagree	Strongly Disagree
21	9	11	1	0

Table 2: Parkinson's Law" existence in working environment

Total	Strongly Agree	Agree	Disagree	Strongly Disagree
21	6	15	0	0

Table 3: Multitasking" creating resource conflict and reducing project performance

Total	Strongly Agree	Agree	Disagree	Strongly Disagree
21	0	13	8	0

From above interpretation table 1,2 and 3, it can be seen that, 52% of respondents agreed and 43% of respondents strongly agreed in case of “student syndrome” existence. Similarly, 71% of respondent were strongly agreed and 29% of respondent agreed upon the existence of the “Parkinson’s Law” and 62% of respondents agreed upon the multitasking is creating resource conflict and reducing project performance. This interpretation shows that, “student syndrome” exists when workers working in flexible time estimates, similarly, Parkinson’s Law also exist in the flexible working environment and Multitasking reduces efficiency and creates resource conflict, finally resulted into reduced project performance in case of time overrun, cost overrun.

Application of Critical Chain Project Management:

Exploitation of Constraint:

The above analysis and interpretation of the human factor variables and Multitasking problem shows that the time estimates considered while scheduling a project can be shorten to aggressive estimates. Generally, Aggressive estimates are made 50% of original (i.e. inflating activity time estimates) estimates. The removed safety time from critical chain and feeding chain are resulted into different types of buffers viz. Project buffer and Feeding buffer. A single project buffer is added at the end of the project network between the last activity and the project deadline. Any delays on the critical chain will partly consume this buffer without having an effect on the project completion date. Consequently, a project buffer acts as a protection of the project completion date which might be variable due to changes in activity durations on the critical chain. Any path of activities merging into the critical chain is called a feeding chain. Feeding buffers are added at the end of feeding chain to protect critical chain against violation in the feeding chains. Here, originally proposed schedule activity time estimates are reduced to 50% and added at the end to make buffers. This is the exploitation of the constraint by sizing and inserting the buffers, which is internal management of time resource.

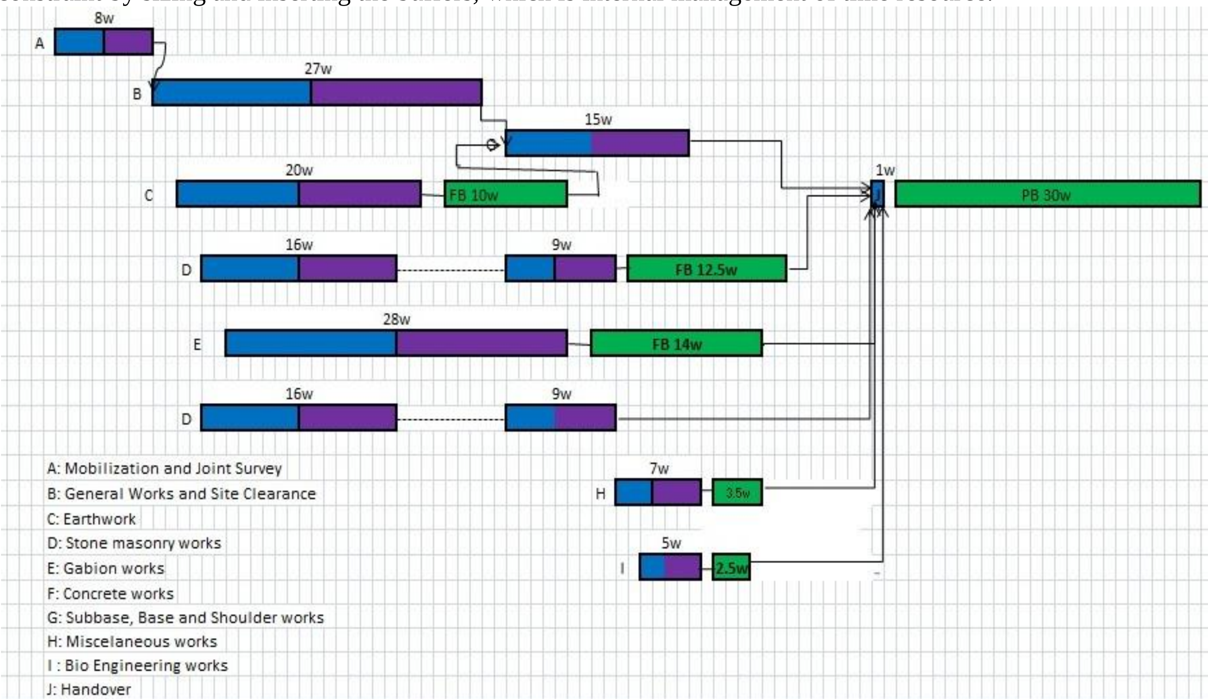

Figure 3: Inserting Buffers to protect the project deadline

Subordination to Above Exploitation:

Figure 3 shows that, the project buffer is added at the end of the project network, project buffer is the summation of the project durations which are removed from half of each activity duration lying on critical chain A-B-G-J. The project buffer acts as a protection of the project completion date which might be variable due to changes in activity durations on critical chain. Similarly, feeding buffers are inserted at the end of each feeding chain which are merging into critical chain, i.e C-G, D-J, E-J, F-J, H-J, I-J. These feeding buffers are also sum of half of each activity duration of feeding chain, which protects the critical chain against the changes in feeding chain. Resource buffers are also inserted into the critical chain activities which are shown in next figure 4.9. The physical meaning of the resource buffers is a warning signals that ensures the timely availability of project resources in critical chain, resource buffer is a virtual buffer and not the time buffers. As, the critical chain needs continuous resources to adjust the progress of activities then, the critical chain activities are subordinated by the required resources supplemented from ideal resources of other non-critical chain (i.e feeding chain).

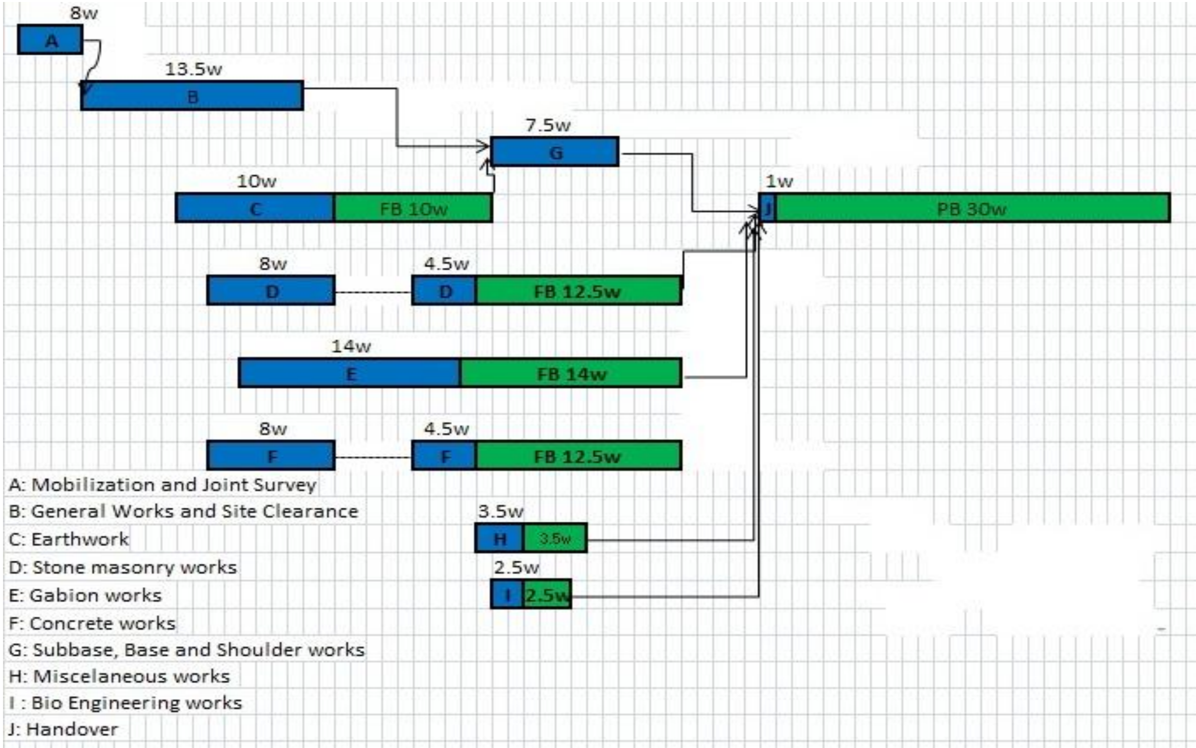

Figure 4: Application of CCPM to case project

Elevating the System Performance:

This is the proposed application of the critical chain project management, which can be analyzed as the critical path is converted into critical chain which has longest duration. The activity time estimates are reduced to half of the original and buffers are created by summing up of the reduced time. Here, Project buffer of duration 30 weeks is inserted at the end of project. This means, the project is supposed to be finished 30 weeks prior to originally proposed deadline. However, there can be delay due to several factors, any delay in the critical chain consumes the project buffer time. Feeding buffers are also inserted at the end of the non-critical chain. Feeding buffer protect the critical chain while non-critical chain merges into critical chain. Resource buffer is like a virtual buffer, which is not time buffer but it is the guarantee of resources which can be applied to critical chain so critical chain will not be affected. Here, elevating the system performance is achieved by exceeding the resources (i.e. adding extra man power, material and equipment) to Critical chain activities, so that critical activities could have boosted progress with continuous availability of resources. The application of CCPM shows that there is possibility of project completion prior to targeted date.

Buffer Penetration Management:

The project buffer of 30 weeks is divided into 3 parts, first 33% part with color code "green" and 2nd part with color code "Yellow" and remaining part with "red". While delay is encountered in critical activities, the project buffer is consumed. The consumption of buffer time within green part resembles no action is needed; the project is within the safe zone. Such as, here critical chain is A-B-G-J, and A has 8 weeks duration, B has 13 ½ weeks, G has 7 ½ weeks and J has 1 week. If Activity A takes 12 weeks to complete and Project buffer is consumed by 4 weeks, which is 13.33% of Total 30-week buffer. That means, project is under control, Buffer consumption is within green zone.

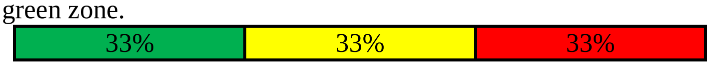

Figure 5: Buffer Penetration Management

When Activity B is taking 18 weeks and still is in process to complete, this means 28 % of total 30-week buffer, and still is in safe zone. If Activity B takes 25 days to complete, which means about 52% of total buffer is consumed, and then buffer consumption penetrates to yellow zone, Project team needs attention to speed up work. Similarly, if Activity G taking 13 days and still is in process to complete, the buffer consumption will be 21 days, this means 70% of total buffer is consumed, and Buffer consumption penetrates into red zone. If Buffer consumption penetrates red zone, there must be stage of emergency and resource buffers are made available to complete the activities within time. This is the best method of monitoring and control of the project, which can improve the project performance.

Bhimdhunga-Lamidanda Road Project:

For this project, the Theory of Constraints (TOC) was applied in generalized form for removing the constraints identified.

This case study is carried out to apply the five focusing steps of the TOC. This study is targeted to crash the project schedule by applying the TOC. Thus, the major work processes are impeded by major constraint i.e Legal constraint. This can be defined as the Restriction of District Coordination Committee (DCC) to collect gravel and boulders from river and quarry sites. This legal control mechanism is made by local government for controlling the excessive excavation of river bed material, erosion controls, landslide control and possible environmental impact in the territory. This policy has restricted to any constructional activities for quarrying the sub-base, base materials from the river territory where Environmental Impact Analysis is not carried out. Thus, the Project is greatly affected by this issue and major work processes like sub-base, base, shoulder and bituminous work is not started till 13 June, 2017.

a. Exploitation of Constraint: The major constraint which are impeding the major work processes are identified as legal constraint impeding the work progress of Sub-grade, sub-base and base course as well as bituminous work. The next step is to exploit the constraint. Exploiting the constraint means the improvement of internal capacity to accelerate the output of the processes. The constraint lying on processes are exploited as following.

- Review of quarry site for possible alternative quarry location and coordination with district coordination committee for extracting of materials from near river bank by stating the project having importance of connectivity of rural areas and implementing under same governmental entity (District Technical Office).
- Setting of aggressive plans for completing the major work processes (sub-grade, sub-base, base and bituminous works) within specified periods
- Removal of minor constraints (like economic, environmental, socio-political issues) which can disturb to major process implementation
- Provision of full staffing at the constraint processes with surplus/backups.
- Mobilization of sufficient skilled workers with support
- Setting of Management plan for stock piling of materials (river bed materials, crusher run materials, sand, cement, reinforcement bars, bitumen), provision for labor camp, facilities, health and safety.
- 24/7 operation at the constraints (day/night shift).
- Ensuring availability of gravel materials, bituminous materials and equipment
- Uninterrupted consumables at constraint
- Rapid material movement before/after the constraint.
- Monitoring the progress & improvement over time.

b. Subordination to above exploitation: To achieve the maximum performance of the project along the constraints, above exploitation decision is made. For such exploitation, other resources are needed to add within the internal project environment. Here, the work processes like sub-grade, sub-base, base and bituminous works are not started till date, thus, several subordinations are needed to assisting for completing within revised intended date of completion. Following subordination are made with help of other non-constraint processes.

- Transferring the resources to constraint processes which are being used by non-constraint processes like earthworks, Stone masonry works, gabion masonry works and those activities have available float to complete, so that sufficiency of resources to sub-grade, sub-base, base and bituminous works are maintained.
- Backup system of material, manpower and equipment are generated.
- Immediate problem-solving team is formed and set under alarm condition.
- User committee members are motivated to solve social, political and other environmental issues.
- Installing management hotlines and plant alarm at the constraint.
- Monitoring the work progress to track it at day/night shift.
- Expediting as required to ensure uninterrupted supply to constraint.
- Educating staff: Constraint first (tooling, maintenance and material movement).
- Ensuring raw material availability at all times
- Ensuring the uninterrupted supply of resources to constraint at all times.

c. Elevating the system Performance: If the performance of the work processes is not improved by managing and effective utilization of the internal resources, then resources are added to constraint processes from outer environment. Here, it has been proposed different elevating factors to improve the performance.

- Estimation of present and future capacity requirements.
- Investment to hire more skilled manpower to expedite the performance of work processes
- Investment to supplying of quality of material without interruption.
- Adding extra excavators, dumpers, tractors, rollers, graders and other construction equipment so that it can be ensured the equipment availability at all times.
- Establishment of efficient mobile crusher to produce materials.
- Planning and execution of expansion-number of machine, operators, spaces etc.

- Upgrading of existing machine if feasible.
- Supplying of extra material from another source, so that surplus of material is ensured.
- Purchasing sufficient facilitating materials to workers, so that working morale of workers can be increased.
- Establishment of well facilitated site camp to operate official works and worker camps with medical facilities.
- Investment to mobilize local public relation officer to solve socio-political issues.
- Stocking of sufficient construction materials, fuel and other required accessories.
- Investment toward the coordination expenses coordinating all the stakeholders.

Conclusion:

The Conclusion of this study can be summarized as follows:

In study of Sankosh-Tipling Road project, the Theory of Constraint (TOC) was applied considering the human behavior factors like Pakrinson's Law and Student syndrome to manipulate the activity time estimate to aggressive time estimate by creating the time buffers in Critical Chain Project Management (CCPM). With application of Critical Chain Project Management (CCPM), the project was supposed to be finished 30 weeks prior to originally estimated date of completion if it has ideal condition. However, several delay factors consume the time buffer like feeding buffers as well as project buffer can make project delay rather than ideal condition. But, CCPM has assumed that, ensuring project completion by early warning of buffer time consumption and consequently timely completion of project as intended date of completion.

In study of Bhimdhunga-Lamidanda Road Project, the generalized form of Theory of Constraint (TOC) was applied to overcome the constraints identified. Exploitation of constraint was applied for improvement of internal capacity to accelerate the output of the processes. Similarly, Subordination was proposed for assuring the availability of resources within internal project environment. If performance of work process is not improved by managing and effective utilization of the internal resources, extra resources were proposed for its addition to constraint i.e. elevating system constraint. Thus, with application of Theory of Constraint (TOC), the project was supposed to be finished within intended date of completion.

The overall study of application of TOC and CCPM has shown that, Considering the human behavior factors in construction, the use of time buffers (feeding and Project buffers) and resource buffers as well as the systematic process of removing the project constraints, the overall project duration was supposed to shorten prior to intended date of completion. If the project is completed prior to intended date of completion, it saves time, saves resources like man power, material, time value of money thus improving the overall performance of the project.

Recommendations:

Study concludes that constraint should be identified and must be removed for improving the project performances. So, Following Recommendations are made for successful project management of construction project.

- In a project management context, the identification step must locate those critical resources and interdependent activities that will have the largest negative impact on the project's duration, cost or scope. Identifying the major problem helps to decide the future action to be taken.
- The exploitation of constraint must address the critical activities and resources are scheduled and implemented in an optimal way. The internal resource capacity must be strengthening to achieve the greater system performance.
- Subordinating the performance of non-constraint, more performance from the constraint is achieved, and this translates into more progress of project at the same level of operating expense, and more money on the bottom line. The non-constraint is less efficient; but the project as a whole is more efficient at making performance better. This is a central tenet of the Theory of Constraints that the optimal performance of the whole system doesn't come from sub-optimizing each individual resource.
- In the case that the project's likely output is deemed to be unsatisfactory the constraint must be elevated, i.e. critical resources must be added or activity dependencies resolved.
- If by elevation of the identified constraint the critical activities and resources lose their criticality, one goes back to the identification step in order to identify the new constraint.

These processes are very fruitful to break the constraint and this is the milestone approach of project management. To have a good understanding of the identified constraints at the planning stages, it is suggested the project management to have the constraints documented and to consider these constraints in the relevant project planning agenda and schedule as well as the designing of the organizational structure. At the implementation stage, the project team should keep track of the progress and be aware of the constraints they encounter. The management should ensure that enough resources, which include money, facilities, staffing and effort, are allocated to decrease the limitations from the constraints encountered.

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