Application of Theory of Constraints (TOC) in Power Generation to Increase Overhaul Maintenance Performance and to Strengthen Overhaul Management Process

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Abstract. Theory of Constraints (TOC) is a new concept of overhaul management in power generation. It has been effectively used in various industrial activities. This paper describes the idea of how the TOC is applicable to improve the overhaul management dealing with several constraints with a case of power plant overhaul performance. TOC uses all five application tools to analyze a system or situation to identify a core problem, develop a solution for it, and determine how to implement that solution. These applications are CRT (Current Reality Tree), EC (Evaporating Cloud), FRT (Future Reality Tree), PRT (Prerequisite Tree), and TT (Transition Tree). The result of the study has shown several main factors causing the achievement of power generation overhaul performance not optimum. Based on the main causes that have been identified, it will give also some recommendations for improving the power generation overhaul performance such as personnel competencies acceleration and overhaul management process strengthened.

1. Introduction
The recent era is characterized by Volatility-Uncertainty-Complexity-Ambiguity (VUCA) which has given economic, social, and technology change rapidly. This condition creates a very tight competition where all of the areas competing with each other to achieve their highest performance and efficiency for dominating the competition or just to survive. Besides, this could place continuously both in the present and in the future. Theory of Constraints (TOC) becomes an important theory that focuses on the weakest ring(s) in the chain which are bottlenecks for the entire company and tries to determine the relationship of these bottlenecks. Nowadays, the implementation of TOC has expanded broadly not only focus on factory bottlenecks, production planning, control, and scheduling techniques to become a global management philosophy [1].

Theory of Constraints can be useful to the logistics of medical records in hospitals, the results obtained show a significant increase in the level of service and employee productivity, as well as a reduction of cost and the number of patients’ complaints [2]. The Theory of Constraints also can use to reaching optimal product mix in the furniture manufacturer, as a result, it is found that there are capacity constraints in the firm and the profitability will increase 42% after the elimination of this constrain [3].
In Project management, TOC also used to improve the project performance dealing with time constraints with a case of the 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 [4]. Theory of Constraints is one of the most known theories, which was invented to address chronic problems in the industry, including distribution, engineering, finance, marketing sales, strategy, and change management, which is applicable in any problem-solving situation [5]. Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements which is accomplished through the appropriate application and integration of the project management processes identified for the project and this can enable organizations to execute projects effectively and efficiently [6]. Project work has similarities with overhaul maintenance in power generation. This paper is focused on the Theory of Constraints applications in industry, especially in power generation at overhaul maintenance area, and tries to show how the Theory of Constraints approach can be used in the overhaul maintenance management area to achieve the target of best performance overhaul in power generation. It gave also some recommendations and some opportunities for future research in this area.

Maintenance activity (overhaul) is improvements of the large-scale and thorough production facilities and usually done at intervals a given period. The maintenance overhaul this covering on several activities that interlocked and having very strict quality, cost, and time. Overhaul performance can be seen from the On-Time, On-Cost, and On-Quality indicators as an “iron triangle” in which the project completion process must hold on to three constraints, namely according to the planned costs, according to the scheduled time, and according to the specified specifications. Interestingly, from 1997 to 2009 around 2/3 of the 26 Project Success (PS) publications used an “iron triangle” as an indication of the success of the project. Just starting in 2015 the concept of an “iron triangle” has been added to the success criteria of a project while still setting time, cost, and quality as the basic elements of measuring project success [7]. Overhaul Management is a process of synergy and continuous planning, preparation, implementation, control, monitoring, evaluation, and follow-up plans for the planned outage maintenance (overhaul) program which includes: determination of the scope of work, scheduling, work package, resource requirements (human resources, materials, and tools), supporting facilities, quality planning, budgets and costs, standard communication methods/ procedures, overhaul implementation, reporting and overhaul guarantee [8].

The world of electricity industry changes very fast and faces a daunting challenge in meeting global energy needs. A fundamental change that occurred and becomes trending in the global electricity industry are decarbonization, decentralization, and digitalization which demands the development of environmentally friendly plants, electricity distribution no longer centralized and more efficient in electricity business management such as workforce down-sizing, tools, time constraints, and also maintenance method. The need for reliable and flexible power generation has never been greater. One of the biggest barriers to reliable and more flexibility in power generation is the ability to manage complex power plant equipment maintenance (overhaul). If there is no breakthrough in overhaul management, then the business will be stuck at this point.

2. Method
TOC is an approach that allows a person to create and implement changes systematically so that improvements occur to achieve goals. These changes must be able to answer three basic questions i.e. What to Change?; To What to Change?; How to Cause the Change? [9]. The response to these three questions can be a guide to effectively improve organizational performance [10]. TOC consists of five steps, namely CRT (Current Reality Tree), EC (Evaporating Cloud), FRT (Future Reality Tree), PRT (Prerequisite Tree), and TT (Transition Tree).

TOC method was chosen as an analysis tool because the method refers to managing interrelated Constraints through the Identify Constraints – Exploit Constraints – Subordinate Processes – Elevate Constraints – Repeat Cycle guidelines and focus on system constraints by maintenance implementation.
complex overhaul of power generation. The TOC analysis tool was also chosen because of the compatibility of the method with the culture and conditions in the company where the relationship of data, charts, and analysis is not yet available and does not focus on reducing product variation and waste in the process. This TOC method approach does not require the participation of all company people in total. [11]. The TOC analytical framework of this study started by identification of gap, then perform a situational analysis to get UDE. Next, perform Causal analysis using CRT and EC to answer the question What to Change? and To What to Change?. Later, to visualize and predict the future and action plans’ obstacles also can using FRT and PRT to answer the question To What to Change? And How to Cause the Change?. The implementation of the action plan uses TT to answer the question How to Cause the Change? The TOC analytical framework of this study can be seen in Figure 1.

Figure 1. Analytical Framework.
3. Result and Discussion

First of all, we try do collecting all data from communication with all overhaul key personnel to discuss problems that constrained during overhaul such as project manager, site coordinator, quality control, technician, planner, customer, supplier, purchasing, and others stakeholder. Then, all data can be identified for UnDesireable Effect (UDE) and also entity point as shown in Table 1.

| No | MOST UDE                                | 2016       | 2017       | YEAR     | 2018 | 2019 |
|----|----------------------------------------|------------|------------|----------|------|------|
| 1  | Delay in the completion of job          | 21.18%     | 11.90%     | 0%       | 25.7 %|
| 2  | Rework                                 | 5.2%       | 2.7%       | 3.4%     | 5.4% |
| 3  | Low power output after overhaul         | N/A        | N/A        | 38.46%   | 12%  |
| 4  | Low Efficiency of power plants after overhaul | N/A      | N/A        | 30.76%   | 8%   |
| 5  | Incident during overhaul                | 4          | 4          | 5        | 8    |
| 6  | Incomplete SOP (Standard Operating Procedure) | 85.33%   | 84.18%     | 80.54%   | 81.69%|

Table 1. Identify MOST UDE’s overhaul process.

Table 2 shows that delay of completion job is variety every year. Rework also occurred in every year. The low power and efficiency of power plants after the overhaul began in 2018. The incident during overhaul almost happens every year. Incomplete SOP varies between 80-85% of total complete SOP.

After identifying MOST UDE’s, the next step has created the relationship between UDE and entry point at CRT as shown in Table 2.

| UDE              | Entry Point | 1 | 2 | 3 | 4 | 5 | 6 | Total | % of 6 |
|------------------|-------------|---|---|---|---|---|---|-------|--------|
| A                | √           | - | - | - | - | - | - | 1     | 16.67% |
| B                | √           | - | - | - | - | - | - | 1     | 16.67% |
| C                | √           | √ | - | - | - | - | - | 3     | 50%    |
| D                | √           | √ | √ | √ | √ | - | - | 6     | 100%   |
| E                | √           | √ | √ | √ | √ | - | - | 5     | 83.37% |
| F                | √           | √ | √ | √ | √ | - | - | 5     | 83.37% |
| G                | √           | - | √ | √ | - | - | - | 3     | 50%    |
| H                | √           | √ | √ | √ | - | - | - | 4     | 66.67% |
| I                | √           | √ | - | - | - | - | - | 2     | 33.33% |
| J                | -           | - | √ | √ | - | - | - | 2     | 33.33% |

Table 2. Relationship between UDE and Entry Point at CRT.

Based on Table 2, it can be seen that the entry point “D” has the greatest influence on UDE, with a six UDE from the total of six UDE or with the largest percentage of 83%. If a relationship between entry points and UDE has a percentage of 80% or more, then the potential root cause can be stated as a root cause [9]. Based on that reference, the “D” entry point can be stated as the root cause, but in this study, all potential root causes that have a percentage above 50% will be resolved so that most of the problems that hinder the company’s goals can be resolved properly.

The next step in the Evaporating Cloud (EC) stage is to identify systematic conflicts that follow the root cause, including finding initial solutions to conflicts that arise. Based on the CRT that shown Figure 2 it is found that the root cause to be discussed is below:
- Lack of number of competence personel (entry point D)
- Duration of the overhaul is too long (entry point E)
- A lot number of overhaul project to be accomplished (entry point F)
- Less of the qualified supplier (entry point H)
Evaporating Cloud (EC) use a tool to conflicting the root cause from CRT. The conflict is two opposing causes which have one effect or the same overhaul maintenance performance goal.

Based on the results of the Evaporating Cloud, some initial injection can be taken to achieve the overhaul objectives, including:

- Personnel competencies acceleration program.
- Monitoring and evaluation of the overhaul management process.

After designing the Evaporating Cloud, the next step is to define the Future Reality Tree (FRT) for estimating future conditions that we will achieve. In this FRT, injections will be included to support the successful fulfillment of goals. Table 3 shows the correlation between UDE and FRT Objective:

**Table 3. Relationship between UDE and FRT Objective.**

| No | UDE                                      | FRT Objective                                      |
|----|------------------------------------------|---------------------------------------------------|
| 1  | Delay in the completion of job           | Completion of job on Time                          |
| 2  | Rework                                   | No Rework                                         |
| 3  | Low power output after overhaul          | The output of power plants after overhaul high     |
| 4  | Low Efficiency of power plants after overhaul | The efficiency of power plants after overhaul high |
| 5  | Incident during overhaul                 | No Incident during overhaul                       |
| 6  | Incomplete SOP                           | Complete SOP                                       |

![Diagram of Current Reality Tree (CRT)](image)

**Figure 2.** Diagram of Current Reality Tree (CRT).

The initial injection which has been obtained using EC then used as the initial entity in FRT as shown in Table 3 to change the condition of UDE to DE so that the root cause can be resolved which will lead to the achievement of overhaul maintenance performance.
The next step is to implement a Prerequisite Tree (PRT). Where the application of PRT is to describe the obstacles to achieving the final goal (objectives) and cope with the determination of intermediate objectives. The following are steps application PRT from two initial injections as in Tables 4 and 5.

**Table 4.** List of Obstacle and Intermediate Objective-Personnel competencies acceleration program.

| Obstacle                                      | Intermediate Objective                                      |
|-----------------------------------------------|-------------------------------------------------------------|
| There are no Mentoring guidelines             | Forming a Team as PIC Mentoring Guidelines                   |
| No Training of Trainer (TOT)                  | Availability of TOT Method                                  |
| Junior personnel not willing to learn and mentors not willing to teach | Availability of Reward and Punishment Systems for Training |
| There is no competency mapping of all personnel | Update the Competency Database periodically                  |

Based on Tables 4 and 5, it can be seen what intermediate objectives are needed to achieve the objective "Acceleration of competency enhancement of available personnel". This intermediate objective has obstacles so other intermediate objectives are needed and so on until obtained the last intermediate objective does not have another obstacle.

**Table 5.** List of Obstacles and Intermediate Objectives - Conducting Monitoring and evaluation of the overhaul management process.

| Obstacle                                           | Intermediate Objective                                      |
|----------------------------------------------------|-------------------------------------------------------------|
| Expert personnel has no opportunity to participate in Overhaul Management Evaluation Discussion because of very tight of overhaul schedule | Making the monitoring and evaluation of overhaul schedule with overhaul preparation discussion simultaneously & conduct the virtual meeting |
| No updated guidelines for monitoring and evaluation of overhaul management and no digital platform | Forming a team as PIC to update guidelines for monitoring and evaluation of overhaul management and digitalization process |

To achieve the goal of "Monitoring and evaluation of overhaul management process" there is some intermediate objectives:

1. Making the monitoring and evaluation of overhaul schedule with overhaul preparation discussion simultaneously & conduct the virtual meeting.
   These intermediate objectives are made to overcome Obstacle - Expert personnel has no opportunity to participate in Overhaul Management Evaluation Discussion because of the very tight of overhaul schedule. Intermediate objectives such as:
   - Quality planning improvement.
   - Overhaul the current audit enhancement (Checkpoint monitoring system).
   - Post outage work package and WBS evaluation (apply the effect of a learning curve to reduce activity duration and project length).
2. Forming a team as PIC to update guidelines for monitoring and evaluation of overhaul management and digitalization process.
These intermediate objectives are made to overcome Obstacle - No updated guidelines for monitoring and evaluation of overhaul management and no digital platform. Intermediate objectives such as:

- Resource integration database (manpower, tools, materials, and supplier database).
- Digitalization end to end process.

The last steps of the TOC in the form of implementing an improvement strategy that can be done using the Transition Tree (TT) by determining the specific steps (actions) for each injection that has been determined on the EC and intermediate objectives of the PRT. The specific steps for implementation of two injections of personnel competencies acceleration program and monitoring & evaluation of overhaul management process are forming a team as the person in charge to create mentoring guidelines, availability of TOT method, availability of reward and punishment systems for training, update the Competency Database periodically, making the monitoring and evaluation of overhaul schedule with overhaul preparation discussion simultaneously & conduct the virtual meeting and forming a Team as PIC to update guidelines for monitoring and evaluation of overhaul management and digitalization process. These intermediate objectives need a specific action plan to ensure the achievement of overhaul performance targets using tools Gantt chart or other planning and scheduling chart.

4. Conclusion

It is quite clear that TOC has broad applicability in various industrial activities, brings a new dimension to overhaul management in power generation, and provides an interesting challenge for thinking processes to increase overhaul performance. The analysis results showed several main factors causing the achievement of power generation overhaul performance become not optimum namely the lack number of competence personnel, overhaul duration is too long, a lot number of overhaul projects to be accomplished, and less of the qualified supplier. Based on the main causes that have been identified, it given also some recommendations for improving the power generation overhaul performance such as personnel competencies acceleration program and strengthened of overhaul maintenance management process by quality planning improvement, overhaul current audit (Checkpoint monitoring system), post outage work package and WBS evaluation (apply the effect of a learning curve to reduce activity duration and project length), resource integration database (manpower, tools, materials, and supplier database) and digitalization end to end process. By ensuring the implementation of all action plans, it can be guaranteed to increase overhaul maintenance performance and to strengthen the overhaul management process in power generation. Further research can be discussed in the trade-off between the iron triangle indicator in overhaul management (on time, on cost, on quality).

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