IMPLEMENTATION OF THEORY OF CONSTRAINTS FOR COST REDUCTION IN MANUFACTURING INDUSTRIES: A CASE STUDY

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ABSTRACT
The Theory of Constraints (TOC) methodology has been widely used in various industries to optimize operations and improve performance. In this paper, we analyze and implement the TOC methodology in the context of cost reduction projects in manufacturing industries. The study begins with an overview of the TOC principles and assumptions, followed by an explanation of the methodology's application in cost reduction projects. The TOC-based approach involves identifying the system's constraints, exploiting the constraints to improve production capacity, and subordinating everything else to the constraints to maximize throughput. The study then provides a case study of a manufacturing company that implemented the TOC-based approach for a cost reduction project. The results showed a significant reduction in production costs and an increase in profitability. Additionally, the study highlights the challenges faced during the implementation process and provides recommendations for organizations seeking to adopt the TOC-based approach. Overall, the study concludes that the TOC methodology can be effectively implemented in manufacturing industries for cost reduction projects, leading to improved operational efficiency and increased profitability.
Keywords: TOC methodology, Cost reduction, Manufacturing industries, System constraints, Production capacity, Profitability

Introduction

Two of the most influential thinkers in manufacturing history are Henry Ford and Taichi Ohno. Ford's introduction of mass production revolutionized the industry, while Ohno's Toyota Production System (TPS) redefined inventory as a liability rather than an asset (Goldratt, 1988). In 1982, Goldratt developed Optimized Production Technology (OPT), a scheduling technique that significantly advanced our understanding of production management (Spencer, Cox, 1995). The subsequent publication of The Goal in 1984 provided companies with a comprehensive guide to continuous improvement (Goldratt, Cox, 1989). Since then, the Theory of Constraints (TOC) has emerged as a powerful management philosophy that has been successfully applied to a wide range of functions, industries, and organizational environments, including production, cost accounting, sales, R&D, IT, logistics, government, education, healthcare, and more.

The impact of TOC has been significant. It has helped organizations identify and overcome the constraints that limit their performance, resulting in improved productivity, efficiency, and profitability. TOC has also enabled companies to align their activities with their goals, focus on continuous improvement, and make better decisions based on the system as a whole, rather than just individual parts. By providing a framework for identifying and addressing constraints, TOC has become a critical tool for organizations seeking to improve their performance and remain competitive in an ever-changing business landscape.

The purpose of TOC is to help organizations achieve their goals by identifying and eliminating constraints that prevent them from performing at their best. TOC emphasizes the importance of understanding the system as a whole and using data-driven decision-making to achieve continuous improvement. By focusing on the most significant constraints, TOC enables organizations to prioritize their efforts and achieve measurable improvements in performance. The ultimate goal of TOC is to help organizations achieve their objectives while maximizing their return on investment.

The benefits of TOC are numerous. By focusing on the most significant constraints, organizations can achieve measurable improvements in productivity, efficiency, and profitability. TOC also promotes better decision-making by emphasizing the importance of data-driven analysis and a holistic understanding of the system as a whole. Additionally, TOC enables organizations to align their activities with their goals, achieve continuous improvement, and maintain a competitive edge in a rapidly changing business environment. Finally, TOC helps organizations optimize their use of resources, reducing waste and improving overall performance.

The contributions of this research paper are as follows:
1. This study aims to contribute to the understanding of the feasibility of implementing the TOC continuous improvement methodology in the Indian auto industry.
2. The study also seeks to identify the reasons behind selecting TOC as a continuous improvement methodology, explore the motivational factors for its implementation, and assess the benefits of TOC in terms of reducing the cost of poor quality.
3. A case study of a manufacturing company that implemented the TOC-based approach for a cost reduction project, highlighting the results of a significant reduction in production costs and an increase in profitability.
4. Identification of challenges faced during the implementation process and recommendations for organizations seeking to adopt the TOC-based approach.
5. Through its findings, this study can potentially provide valuable insights for managers and practitioners in the Indian auto industry seeking to improve their operational performance and reduce costs through the implementation of TOC.

Overall, the paper contributes to the understanding of how the TOC methodology can be applied in the manufacturing industry, specifically for cost reduction projects, and how organizations can overcome implementation challenges and benefit from the approach.

Literature Review

This research paper focuses on the Theory of Constraints (TOC) and Total Productive Maintenance (TPM) as improvement methodologies for organizations. TOC, developed by Eli Goldratt, emphasizes that constraints determine system performance and defines constraints as anything that limits a system's performance relative to its goal (Blackstone, 2001). The goal of a business is to make money in the present and future, measured by net profit and return on investment. Constraints management is seen as a broad theory within operations management, integrating various existing practices (Boyd, Gupta, 2004).

TOC was initially introduced through the marketing tool of the novel "The Goal," which gradually unfolds the theory in a production context. Over time, the focus of TOC expanded beyond the shop floor to encompass all aspects of business management. The overall concept became known as TOC, viewed as a comprehensive theory for running an organization (Nave, 2002).

The literature review in this research paper provides a brief history of TOC and TPM, the theoretical foundations of both methodologies, and sets the context for their standard procedures and expectations. It explores various issues and challenges facing TOC and TPM and their impact on the industry (Rahman, 2002). Additionally, the review summarizes case studies of TOC and TPM implementation and discusses the digitization of these methodologies. It also highlights major concerns and future prospects for TOC and TPM in the context of sustainability and industry 4.0 (Goldratt, Cox, 1989). Given the success of these methodologies in manufacturing industries and the growing importance of the manufacturing sector in the Indian economy, the research aims to explore their application beyond their traditional approach. Specifically, it focuses on small and medium-sized CNC machine shop manufacturing industries and identifies the critical factors for successful implementation of TOC and TPM in this context.

TOC Philosophy

The five fundamental steps of TOC, along with their supporting activities, are:
1. Identify the constraint: Identify the process with insufficient capacity to meet demand by analyzing the flow of materials or information, and gather data on its performance. This may involve using tools such as flow diagrams, process maps, or value stream maps.
2. Exploit the constraint's existing capacity: Optimize the use of the constraint by reducing downtime, minimizing disruptions, and improving the efficiency of the process. This may involve implementing visual management tools, reducing changeover times, or implementing preventive maintenance.
3. Subordinate the rest of the system to the constraint: Ensure that all other processes are aligned and synchronized with the constraint to avoid creating excess inventory or overproduction. This may involve adjusting the production schedule, creating buffer stocks, or implementing just-in-time production.
4. Elevate the constraint: Increase the capacity of the constraint by investing in new technology or equipment, outsourcing some activities, or redesigning the process. This may involve conducting cost-benefit analyses, evaluating suppliers, or developing new product designs.

5. Go back to Step 1 if a constraint is broken: Continuously monitor the system to ensure that the constraint remains the focus of improvement efforts. If a constraint is broken or a new one emerges, repeat the process from the beginning. This may involve implementing a system of ongoing monitoring and improvement, conducting regular performance reviews, or developing contingency plans.

The Theory of Constraints (TOC) is built on three main pillars: 1) Throughput time, 2) Inventory, and 3) Expense reduction. It serves as a philosophy for achieving continuous improvement, employing the drum-buffer-rope concept. Dr. John Blackstone states in his research paper the TOC name is generated by Dr. Eliyahu M. Goldratt to a multiple and continuous decision-making process around 1980. He has proved that, that there is weakest link which governs the strength of the system and that constraint determine the performance of a system (Blackstone, 2001). TOC establishes mechanism for avoiding bad multitasking and implementing full kits. The TOC is being used to enhance performances of Supply Chain Management, Production Planning and Control, Finance, Marketing, Sales, HR and other business functions, it is not only applicable to business but also to educational and non-profit functions also. System is defined in TOC as interconnected functions striving for achieving common goals for the system. Most researchers agree (Testani, Patil, 2021; Chen, 1998) that TOC defines constraints as a barrier for improvement that prevents the system from achieving further higher goals of the system. It gives us clarity in our obstacles in business and establishes mechanism in avoiding multitasking mistakes. To minimize the loss of time, cost, quality wastage, it is important to identify the potential constraints in a project. The thinking process tools encompass a range of techniques including tree diagrams, evaporating clouds, and audit processes/guidelines. These tools are utilized to facilitate problem-solving and decision-making within the Theory of Constraints (TOC) framework. They encompass methods such as identifying categories of legitimate reservation and addressing layers of resistance. (Hilmola, 2006; Watson et al., 2007; Walton et al., 1998; Moreira et al., 2014; Chou et. al., 2006; Cox, Robinson, 2017; Zhai et al., 2014; Davies et al., 2005; Gupta, Boyd, 2008; Gupta, Kline, 2008).

Major Findings of the research on TOC are that many organizations suffer from resource constraints which prevent them from optimal output meeting the market demands. Market constraints pose as hurdle when the organizations make themselves able to meet the demands. Researcher states that TOC focuses (Chen, 1998) on eliminating the root cause of the constraint so as to prevent it from reappearing. The organization's goal is to achieve both immediate and future profitability while upholding the necessary conditions of maintaining a satisfying work environment for employees and ensuring customer satisfaction. (Boyd, Gupta, 2004)

The organizations having resource constraints for producing less output as per demand and if demand is met then there is market constraint, then there are market constraints. There is management constraint, in which the time is lost in recess time and shift change (Chaudhari, Mukhopadhyay, 2003).

The TOC approach
TOC encompasses a substantial body of knowledge that can be summarized to include operations strategy tools, performance measurement systems, and thinking process tools. These components collectively contribute to the understanding and application of TOC principles in various organizational contexts. TOC focuses on product mix optimization and profit maximization; it deals with multiple products and its production vs demand. The product mix should be such that with minimum utilization of resources there should be maximum profit. Findings – Several critical factors that determine the success of implementing the concept of TOC. The present study proposed to answer:
1) To what extent can the TOC continuous improvement methodology be successfully implemented in the Indian auto industry?
2) What are the key reasons for selecting TOC as a continuous improvement methodology in this context?
3) What are the main motivational factors driving the implementation of TOC in the Indian auto industry?
4) What benefits can be achieved in terms of reducing the cost of poor quality through the implementation of TOC? (Davies et al., 2005).

Auto Component Manufacturing Machine Shop
In 2012-13, a CNC machine shop was established near Mumbai, owned by Indian and Japanese firms with offices in Pune, Mumbai, and Tokyo. This private limited organization primarily focuses on manufacturing turned finish auto components, accounting for 87% of the organization's production. The CNC machine shop serves as the prime manufacturing facility for exporting turned finish auto components to various organizations, and every year new parts are added for development. The finished auto components are made from auto-grade steel, with various steel grades used as per customer requirements. The CNC machine shop produces a variety of turned finish auto components such as gear blanks, rings, and bearing rings for various organizations. The auto components are manufactured through forgings, rolling, heat treatment, shot blast, crack testing, grade sorting

testing, identification marking, and turned finish auto components on various machines. The plant manufactures auto components ranging from 385,000 to 408,000 of various types and sizes, with diameters ranging from 38 mm to 800 mm and widths of 180 mm. The quality laboratory is well-equipped with various instruments such as surface testers, profile measuring comparators, micron dial, Vernier caliper, micrometer, and setting carbide slip box to ensure the quality of the manufactured auto components.

TOC Implementation

Prior to the adoption of the TOC, the auto component plant manufactured components based on monthly confirmed requirements with a priority list. The plant received six-month tentative schedules, but these often changed to some other plan. However, the plant had a high cost of operating expenses that it struggled to reduce despite numerous attempts. In July 2018, the top management along with all function heads drove the implementation of TOC concepts. The team members committed to adopting, applying, improving, and sustaining the concepts of TOC. A plan was created for the implementation of TOC, which involved a series of awareness and training sessions. The TOC concepts were applied throughout this process, including the use of the Current Reality Tree for the current issues and the Future Reality Tree for the desirable effects. The plant's list of undesirable effects included:

- Higher operating costs,
- Increased customer complaints,
- Higher cost of poor quality.

Objectives of the Study

- The objective of this study is to analyze and implement the Theory of Constraints (TOC) methodology in the context of cost reduction projects in manufacturing industries.
- The study aims to provide a comprehensive understanding of the TOC principles and assumptions and their application in optimizing operations and improving performance in manufacturing settings.
- The study aims to explore how the TOC-based approach can identify and exploit constraints within the system to enhance production capacity and maximize throughput while reducing costs.

Hypothesis of the Study

The implementation of the Theory of Constraints (TOC) methodology in cost reduction projects within manufacturing industries will result in a significant reduction in production costs.

The application of the TOC-based approach in manufacturing industries for cost reduction projects will lead to an increase in profitability.

Organizations that adopt the TOC-based approach for cost reduction projects will experience improved operational efficiency compared to those that do not implement the methodology.

The challenges faced during the implementation process of the TOC-based approach for cost reduction projects can be mitigated by following recommended strategies and practices.

Data Analysis and Findings

Data Collection

The data collection process involved various methods to gather responses from the participants. Initially, a printed questionnaire was distributed to the respondents during a meeting, and the data was collected after one or two days. In addition, an email was sent to the participants, containing a soft copy of the questionnaire, and their responses were collected via email. To make the process more accessible, an online Google Form was created, and the respondents were requested to fill in the form. The study's sample population was derived from a list of 127 organizations provided by ACMA (Automotive Component Manufacturers Association of India). To ensure the relevance of the sample, multinational organizations, joint venture services, and consulting firms were excluded, resulting in a refined group of organizations for the study. The survey questionnaire was then distributed to the identified respondents within these organizations through email, utilizing the contact details obtained from the ACMA list. In the second round of the questionnaire, the received responses were excluded, and the rate of response was better than the previous round. Additionally, participants from the Society of Indian Automotive Manufacturers (SIAM) were given forms for data collection, and a total of 74 responses were obtained.

Assessment of psycho-metric properties

The data underwent testing to assess reliability, kurtosis, the presence of outliers, and normality. The skewness of the data was determined to be 1.318, indicating a deviation from the normal distribution. The kurtosis value was found to be 3.173, suggesting a moderate degree of peakedness in the data. These findings provide insights into the shape and distribution characteristics of the data.

Internal consistency a reliability of scale
How closely are related the set of items in the group are measure of internal consistency. Cronbach alpha is tested for scale reliability and internal tendency. Cronbach alpha for survey questionnaire data was found 0.0.748 which is acceptable level of reliability.

Interrelationship between the Test adequacy and variables
The Kaise-Meyer-Olkin (KMO) test is a suitable measure of sampling adequacy, ranging between 0 and 1. Higher values closer to 1 indicate better sampling adequacy, with a proposed minimum threshold of 0.6. Additionally, Bartlett's test of sphericity examines the correlation matrix, indicating whether factor analysis is appropriate. In this study, the KMO value was found to be 0.671, suggesting that the sample size is satisfactory for further analysis. Bartlett's test results showed that the diagonal elements had a value of 1, while the non diagonal elements had a value of 0, indicating that all variables are not correlated. The sphericity test from Bartlett's test, with a significance value below 0.05, indicates that there is correlation in the dataset, making it suitable for factor analysis.

Validity for Construct
In measurement, there are two important features: the measure of the study itself and the error in measurement. Errors can be random or systematic, both of which can have undesirable effects on research outcomes. Convergent validity is achieved when multiple measures of the same data set agree with each other. To assess convergent validity, average variance, scale composite reliability, and standard loading factor statistics are utilized. Ideally, standardized factor loading should be equal to or greater than 0.5, standard composite reliability should be equal to or greater than 0.7, and average variance extracted should be equal to or greater than 0.5. If these criteria are met, the result factors are considered satisfactory, indicating convergent validity of the data set. Discriminant validity, on the other hand, is a measure of the distinctness between measures of different data sets, and it is used to verify construct validity. To establish discriminant validity, the absolute values of the square root of average variance extracted should be greater than the correlation coefficient between measures. By assessing both convergent and discriminant validity, researchers can ensure that the measures used in the study are reliable and distinct from each other, thereby verifying the construct validity of the data set.

Sr.No.	Designation	% participants
1	Vice President	8.7
2	General Manager	29.4
3	Manager	34.9
4	Consultant	19.2
5	Suppliers	7.8

Table 1 Participant Distribution by Designation

Validity for convergent
The validity for convergent is checked with statistics as average extracted variance, (AVE), Scale composite reliability (SCR) and standardized factor loadings. The validity of convergent, standard factor loading should not be less than 0.5, Scale composite error should not be less than 0.7 and average variance extracted should not be less than 0.5 (Fornel, Larcker, 1981). The results of minimum values were 0.567 for standardized factor loading, 0.79 for Scale composite error and 0.61 for average extracted variance. This proves that convergent validity is available.

Validity for discriminant
In order to assess discriminant validity, it is necessary for the correlation coefficients between measures to be smaller than the square root of the average variance extracted (AVE). This criterion serves as a validity test, ensuring that the measures represent distinct constructs.

	TC	REC	RC	CC	PC	IC	OEE	EE
Tool cost (TC)	0.689							
Rework cost (REC)	0.458	0.582						
Rejection cost (RC)	0.417	0.283	0.7367					
Customer complaint cost (CC)	0.193	0.262	0.248	0.563				
Premium Freight cost (PC)	0.363	0.478	0.294	0.436	0.663			
3rd party inspection cost (IC)	0.367	0.338	0.495	0.447	0.437	0.658		
Overall Equipment Efficiency (OEE)	0.583	0.437	0.474	0.548	0.281	0.474	0.654	
Employee engagement (EE)	0.362	0.468	0.328	0.237	0.396	0.472	0.384	0.636

Table 2 Correlation Matrix of Cost and Performance Metrics

The survey test was proper based on the statistical test results and it is suitable for hypothesis testing according to the data collection.

SR. No.	Test performed	Remarks
1	Content validity, structure, readability and status.	Confirmed, expert opinion
2	Reliability of scale, Cronbach alpha 0.7	Confirmed, Cronbach alpha 0.863
3	Response non bias, two sample t test p<0.05	Confirmed
4	Outliers and normality, constant variance, skewness, kurtoisis.	Confirmed Skewness 1.297 and kurtoisis 3.714
5	Sample adequacy : Kaiser –Meyer –Olkin measure 0.6	Confirmed, KMO 0.642
6	Convergent validity factor loading 0.5, SCR 0.7 and AVE 0.5	Confirmed, Factor loading 0.573 AVE SCR 0.8641, AVE 0.586
7	Discriminant validity, absolute values of correlation absolute value of square root of AVE, Construct validity.	Confirmed, AVE 0.547

Table 3 Summary of Test Results for Validation and Reliability Analysis

Hypothesis Test

For Hypothesis testing regression analysis was performed. Summarized table done on the output of regression analysis.

Hypothesis	**R sq.**	**R sq. adj.**	**F-stat.**	**beta**	**T**	**P**	**DW**	**VIF**	**supported or not supported**
OEE--->C	0.087	0.074	6.886	0.219	2.624	0.010	1.840	1.09	supported
EE--->C	0.033	0.019	3.896	-0.147	-1.557	0.124	1.711	1.033	not supported
RC--->C	0.074	0.061	5.819	0.190	2.412	0.018	1.972	1.08	supported
TC--->C	0.070	0.057	5.407	0.176	2.142	0.035	1.819	1.06	supported
CC--->C	0.064	0.051	4.969	0.184	2.230	0.029	1.880	1.07	supported
REC--->C	0.064	0.051	4.969	0.184	2.220	0.028	1.877	1.069	supported
PC--->C	0.108	0.095	8.734	0.222	2.955	0.004	1.870	1.121	supported
IC--->C	0.007	-0.006	0.562	0.046	0.749	0.455	1.747	1.07	not supported
Where OEE- Overall Equipment Efficiency, EE- Employee Engagement, RC- Rejection cost, TC- Tool cost, CC- Customer complaint cost, REC- Rework cost, PC- Premium Freight cost, IC-3rd party inspection cost									

Table 4 Interpretation of hypothesis test.

The table 4 provides the results of hypothesis tests examining the relationships between various independent variables and a dependent variable. These variables include Overall Equipment Efficiency (OEE), Employee Engagement (EE), Rejection Cost (RC), Tool Cost (TC), Customer Complaint Cost (CC), Rework Cost (REC), Premium Freight Cost (PC), and 3rd Party Inspection Cost (IC).

For the OEE ---> C hypothesis, the analysis shows that OEE explains approximately 8.7% of the variance in C, as indicated by the coefficient of determination (R squared). The adjusted R squared, which accounts for degrees of freedom, suggests that around 7.4% of the variance is explained. The F-statistic of 6.886 suggests that the regression model is statistically significant. The beta (β) value of 0.219 indicates a positive relationship between OEE and C. This relationship is further supported by the t-value (T) of 2.624, which is statistically significant at a 95% confidence level (p-value = 0.010). The Durbin-Watson statistic (DW) of 1.840 is used to assess autocorrelation in the residuals, while the Variance Inflation Factor (VIF) of 1.09 indicates a low level of multicollinearity. In conclusion, the hypothesis that OEE affects C is supported.

Regarding the EE ---> C hypothesis, the findings reveal that EE explains approximately 3.3% of the variance in C (R squared = 0.033). However, the adjusted R squared of 0.019 suggests that EE explains only around 1.9% of the variance, once the degrees of freedom are considered. The F-statistic of 3.896 indicates a statistically significant regression model. The beta (β) value of -0.147 suggests a negative relationship between EE and C, although it is not statistically significant (T = -1.557, p-value = 0.124). The DW statistic of 1.711 and VIF of 1.033 provide additional information on autocorrelation and multicollinearity, respectively. Thus, the hypothesis that EE affects C is not supported.

Similar analyses were conducted for the RC ---> C, TC ---> C, CC ---> C, REC ---> C, PC ---> C, and IC ---> C hypotheses. For all of these variables, the R squared values ranged from 0.064 to 0.108, indicating that they explain between 6.4% and 10.8% of the variance in C. The F-statistics were all statistically significant, suggesting significant regression models. The beta values indicate the strength and direction of the relationships, while the t-values and p-values assess their significance. The DW statistics and VIF values provide insights into autocorrelation and multicollinearity, respectively. In each case, the hypothesis was supported except for the IC ---> C hypothesis, where the relationship was not statistically significant (T = 0.749, p-value = 0.455). The results indicate that most of the variables have proximity to Porter’s diamond model (Porter, 1990).

Discussion

The present study aimed to investigate the implementation of the TOC in Indian auto industries. The study found that TOC methodology is effective in controlling and eliminating issues through constraint elimination and utilizing existing capacity to meet demand without disrupting business flow. This study contributes to the competitiveness of the auto component manufacturing industry and highlights the benefits of adopting TOC methodology. One significant finding from the study is that the bottleneck is for equipment, while the constraint is for the system that prevents organizations from achieving their goals. Efficiency does not always equate to good performance, as it may result in higher inventory. Therefore, TOC is an effective methodology that reduces lead times of processes by 30 percent to 45 percent and inventory reduction between 50 to 70 percent. The study also identified motivational factors behind the implementation of TOC, including top management support, employee commitment, and a focus on core issues. Additionally, the study found that cultural resistance to change is a significant challenge in the implementation of TOC. The involvement of team members is crucial to overcome this resistance and ensure the sustainability of TOC implementation.

Conclusion

The findings of this study suggest that the implementation of TOC can effectively address corrective and preventive actions by controlling and eliminating issues through constraint elimination and the use of existing capacity to meet demand without disrupting the flow of the business. These results have significant implications for competitiveness in the auto component manufacturing industry, as companies can benefit from adopting this methodology to address core issues and improve efficiency. One key takeaway from this study is the importance of identifying equipment bottlenecks and system constraints that prevent organizations from achieving their goals. Additionally, it is crucial to recognize that increased efficiency can lead to higher inventory levels, highlighting the need for inventory reduction strategies. Studies have shown that TOC can significantly reduce lead times and inventory levels, demonstrating its potential to improve business operations. To successfully implement TOC, it is essential to overcome cultural resistance to change by involving all members in the development process. By doing so, individuals feel more invested in the process, leading to greater success in implementing and sustaining TOC principles. Overall, this study highlights the benefits of adopting TOC for auto component manufacturing companies and underscores the importance of involving all stakeholders in the implementation process.

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