Application of TOC Strategy Using Simulation: Case of the Indian Automobile Component Manufacturing Firm

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Abstract

Improved productivity, resource utilization, and efficiency are crucial for the industries working with batch production systems and have attracted growing interest from academia and practice. Five focusing steps approach (FFS) of the Theory of Constraints (TOC) is considered a reliable solution to achieve these ends by effectively elevating the constraint within the system. Although earlier studies highlighted significant advantages of FFS to the manufacturing firms that adopt it, empirical validation from the real-life cases about these benefits is unaddressed in the literature. Most of the studies on TOC concepts are found to have utilized hypothetical cases to demonstrate their applicability. However, this study successfully implemented the simulation-based TOC application in the real-life case of the Indian automobile component manufacturing firms using a resource reallocation strategy to elevate the constraint. A simulation model of the firm under study is created in a discrete event simulation software, ARENA©. The simulation results show that the TOC implementation resulted in an improved manufacturing performance viz. Throughput and resource utilization. The results also establish that the application of TOC reduces the lead time and shown a positively productive efficiency.

Keywords
TOC, Reallocation Strategy, Simulation, Manufacturing Performance, Case Study.

1. Introduction
The concept of Theory of Constraints (TOC) emerged with the pioneering work by Dr. Eliyahu Goldratt in 1980 when Goldratt along with his team, developed a production programming software- *"Optimized Production Technology (OPT)"* for optimizing the operations of production systems to enhance the profit margins of the plant (Cox III and Schleier, 2010; Goldratt, 1980; Plenert, 1993; Rabbani and Tanhaie, 2015). Dr. Goldratt further published the book entitled "*The Goal"* to introduce the concepts for governing manufacturing in an optimal manner by adopting the continuous improvement techniques for achieving competitive manufacturing performances (Goldratt and Cox, 1984). The authors provided a structured approach called 'Five Focusing Steps (FFS)' for managing the bottlenecks in the system through the adoption of a 'Drum Buffer Rope (DBR)' scheduling approach. The intention behind the emergence of the drum buffer rope and bottleneck management is to avoid the overproduction of non-bottleneck resources (Goldratt and Fox, 1986; Ikeziri *et al.*, 2019). The DBR proposed in TOC aids in improving the utilization of productive resources to enhance the manufacturing firms' financial aspects (Telles *et al.*, 2020).
TOC seeks to maintain keen observation on the constraints in the system to help managers for handling bottlenecks effectively. Therefore, TOC is primarily focusing on maximizing the capacity and availability of the capacity-

constrained resource (CCR) for improving the performance of a manufacturing system using the five focusing steps (Ribeiro *et al.*, 2007). TOC is an approach to effectively manage the resource constraints to overcome the issues regarding manufacturing performances (Patel *et al.*, 2020; Urban and Rogowska, 2020). Thus, improving manufacturing performances lead to improved manufacturing competitiveness which further enhances global competitiveness (Deshmukh, 2016; Dhir and Dhir, 2018; Dohale *et al.*, 2020). Hence, it is essential to identify the manufacturing constraint and expose it using the TOC approach to improve the firms' competitiveness in the global market. Once, the capacity of the bottleneck resource or CCR in manufacturing firms is exposed, the bottleneck shifts to the market from manufacturing (Goldratt, 1994; Goldratt and Cox, 1984; Ikeziri *et al.*, 2019). Various new concepts like thinking processes along with FFS were extended to improvise the systems' performance introduced in the novel *'It's Not Luck'* (Goldratt, 1994). The FFS has amalgamated into the *"Process Of On-Going Improvement (POOGI)"* (Watson *et al.*, 2007). The FFS considered in TOC for determining and managing the constraints are given below.

- Step 1: Identify the system's Constraint
- Step 2: Decide how to exploit the system's Constraint
- Step 3: Subordinate everything else to the above decision
- Step 4: Elevate the system's Constraint
- Step 5: Do not allow inertia to become the system's constraint; go to step-1

The first step in FFS is to determine the CCR - a resource having the maximum possible utilization (Rand, 2000). Thus, the exploitation of the identified system's constraint is carried out in Step 2. Once the constrained resource is determined, then running other resources at a higher production rate is worthless; thus, in Step 3, the planning decision needs to be subordinated to keep the bottleneck resource running. Step 4 comprises the elevation of the system's constraint, i.e., raising or exposing the capacity of constraint resources. Pacheco et al., (2014) have enlisted a total of 25 different strategies to fulfill the objective of step 4. The implication of Step results in removing the initially identified constraint. However, it can cause the system's constraint to shift to some other resource, so Step 5 comprises re-identifying the new bottleneck resource by repeating the process.

Gupta et al. (2002) applied the FFS concept of TOC to a hypothetical case for demonstrating its applicability using a discrete event simulation (DES). Authors in their study created a simulation model of a hypothetical case in ARENA© software. Further, authors created different simulation scenarios to provide insights into the performance measures achieved through the application of the TOC approach. Most of the existing works on TOC using FFS comprises the use of hypothetical cases (Ikeziri *et al.*, 2019). Thus, creating a massive gap in the theory and practice of the TOC concept. The advent of new TOC approaches viz. POOGI, Evaporating Cloud, Throughput Accounting (TA), Thinking Process (TP), etc. results in the lesser utilization of the powerful FFS concept. Thus, to bridge these research gaps, the present study demonstrates the implementation of the proposed FFS approach to the real-life case of the Indian automobile component manufacturing firm using a DES. The present research focuses on complementing the research work by Gupta et al., (2002). In the present study, the reallocation/redistribution strategy of TOC to elevate the constraint is applied for bottleneck management using a DES technique. DES enables us to perform iterative scheduling and empowers with prescriptive tools to freeze a master production schedule (MPS). Duplicate resources that were not roped in the production of parts under consideration were made available by adjusting the production schedule or change MPS without affecting the delivery schedule of any parts. Thus, in reallocation strategy, the production load of bottlenecked resources is shifted to the resources which carry out the same operation without setup changes and has lower utilization (here termed as *duplicate resources*) for improving the manufacturing performances viz. throughput, lead time, and resource utilization (Barlevy, 1997; Pacheco *et al.*, 2014). In this study, using ARENA© software, the reallocation strategy is evaluated by doing reactive scheduling virtually to remove the bottlenecks in the manufacturing system.

The remainder paper is structured as follows. Section 2 illustrates the detailed methodology adopted in this study. The description of the case is given in section 3. The discussion on the results is provided in section 4. Section 5 discusses the research implication of the study. The concluding remark and the direction to conduct future research are given in section 6.

2. Literature Review

A virtual computer model of a system or process under study is created using a Simulation method system (Ali and Murshid, 2016; Banks *et al.*, 2005; Law and Kelton, 1991; McDonald *et al.*, 2012). Simulation is one of the most reliable operations research tools for decision making and validation in the production and operations management domain to maintain the competitiveness of a firm (Junior *et al.*, 2019; Salam and Khan, 2016). Simulation has wide applications in the different fields viz. manufacturing, supply chains, healthcare, military applications, project management, logistics, and transportation (Banks *et al.*, 2005; Datta, 2000). Discrete Event Simulation (DES) technique is used in the present research work to create an "as-is" model of a manufacturing firm under study. DES comprises the change in the state of the system at an asynchronous discrete events of time (Ali and Murshid, 2016; Banks *et al.*, 2005; Schruben and Yücesan, 1993). DES permits users or decision-makers to modify the manufacturing setup virtually. This helps in understanding "whether the proposed manufacturing setup is feasible or not?" Thus, adopting a DES to create a model of manufacturing firm aids in eliminating the financial risk associated with the failure in the actual manufacturing setup change and thereby is cost-effective (Banks *et al.*, 2005; Junior *et al.*, 2019; Portioli-Staudacher *et al.*, 2020; Renna, 2017). TOC involves the setup changes by reallocating manufacturing resources and hence it is economical and effective to create a DES model of a firm for identifying the applicability of different TOC strategies to choose the most appropriate one. Amongst the numerous DES software, ARENA© developed by Rockwell simulation, has been extensively used by researchers due to its advantages (Dias and Oliveira, 2016; Kelton *et al.*, 2004). Thus, the present study utilized ARENA© software to create a replica of the manufacturing firm under study.

3. The Case

3.1 Case Description

The implementation of the proposed TOC approach is illustrated using a case example of Velocity Ltd. company. A pseudonym Velocity is given to withholding the identity of the firm under study for confidentiality reasons. Velocity Ltd. is a Korean based original equipment manufacturer of the manifolds for ACs in cars and located in Pune, India. The velocity Ltd. is a large-scale industry with an annual turnover of ₹. 360 million in 2018-19. The manifolds transfer the conditioned air in the car. Velocity Ltd. typically works in make-to-order (MTO) environment with few of the products in assemble-to-order (ATO) environment. The four major kinds of parts are produced in Velocity Ltd. namely Part 1, Part 2 Part 3, and Part 4. Velocity Ltd. produces these manifolds using a batch production system. In recent, due to a gradual increase in the market demand the firm faces difficulty in fulfilling the quoted customer demand in a stated time. Thus, the firm faces a problem of delayed deliveries led to customer dissatisfaction. The preliminary discussion with the production manager, an expert nominated by the management team of Velocity Ltd., provides detailed insights into the problem, and discussed the issues with improper utilization of the resources. The unbalanced resource utilization reduces the demanded level of throughput in the stated period and significantly increases lead time.

The issue with the improper resource utilization and delayed delivery of a firm is addressed using the TOC approach through a DES technique. DES is adopted to create a virtual model of Velocity Ltd. in ARENA© simulation software using real-time data related to cycle time (CT) of resources corresponding to different parts, the number of parts to be produced (throughput) and the run length of the simulation. Figure 1 shows the simulation model of Velocity Ltd. The data of cycle time is collected using a stop-watch time study. Ten readings for CT of each process are taken at a different time interval, in various shifts, to reduce the biasness in the data (Kanawaty, 1992). The average cycle time is calculated and fed to the simulation model. The cycle time data for Parts are presented in Table 1.

The model is simulated for one month comprising of 25 working days with 7 hours working shift per day. Hence, the run length of the simulation is taken as 175 hrs. equal to the delivery period (lead time) of the parts. The data related to the number of parts to be produced' collected from the expert of the firm and presented in Table 2.

A trial on the simulation model is carried out after feeding the collected data in it to verify and validate the model and it is observed that the model replicates the behavior of an actual system. After validation, a total of four simulation scenarios are created. The first scenario shows the present status of the resource utilization of the firm. From scenario 2 onwards, the bottleneck resources are exposed one by one following the FFS of TOC approach. The results from the simulation scenarios are discussed in the following section.

Table 1. Cycle time Data for Parts

Sr. No.	Process	Resource Name	Cycle Time (in Seconds)										Avg. CT
Part 1													
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	Process 1	Resource 1	25	25	25	25	26	24	26	22	25	25	24.8
2	Process 2	Resource 2	18	19	19	20	18	20	21	18	19	21	19.3
3	Process 3	Resource 3	13	13	18	14	16	15	14	12	11	15	14.1
4	Process 4	Resource 4	21	18	19	19	18	19	19	19	21	18	19.1
5	Process 5	Resource 5	21	20	18	20	20	19	22	18	19	18	19.5
6	Process 6	Resource 6	22	28	29	25	22	26	23	25	26	25	25.1
Part 2													
Sr. No.	Process	Resource Name	**Cycle Time (in Seconds)**										**Avg. CT**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	Process 1	Resource 7	24	25	26	23	22	22	22	25	26	24	23.9
2	Process 2	Resource 8	21	20	26	24	22	23	24	22	29	23	23.4
3	Process 3	Resource 9	12	14	16	16	17	16	15	16	16	17	15.5
4	Process 4	Resource 10	20	18	19	20	19	19	19	17	19	17	18.7
5	Process 5	Resource 11	18	23	17	17	17	19	18	22	22	22	19.5
6	Process 6	Resource 12	11	12	11	10	11	11	13	12	10	12	11.3
7	Process 7	Resource 13	25	23	26	26	25	28	28	21	30	25	25.7
Part 3													
Sr. No.	Process	Resource Name	**Cycle Time (in Seconds)**										**Avg. CT**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	Process 1	Resource 14	22	38	28	24	21	21	35	20	23	21	25.3
2	Process 2	Resource 15	18	17	18	19	18	20	20	18	18	19	18.5
3	Process 3	Resource 16	13	13	13	14	16	13	14	13	13	15	13.7
4	Process 4	Resource 17	13	13	16	13	13	16	14	17	13	13	14.1
5	Process 5	Resource 18	27	27	24	29	28	29	26	26	29	25	27
6	Process 6	Resource 19	7	7	6	6	6	6	8	6	7	6	6.5
7	Process 7	Resource 20	23	21	21	26	19	20	23	19	18	19	20.9
Part 4													
Sr. No.	Process	Resource Name	**Cycle Time (in Seconds)**										**Avg. CT**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	Process 1	Resource 21	16	16	17	16	15	16	16	15	14	15	15.6
2	Process 2	Resource 22	24	19	16	18	18	17	17	19	15	26	18.9
3	Process 3	Resource 23	23	25	24	27	24	25	25	28	26	27	25.4
4	Process 4	Resource 24	20	14	18	13	13	17	11	12	13	11	14.2
5	Process 5	Resource 25	20	24	24	25	29	27	29	28	31	32	26.9
6	Process 6	Resource 26	25	23	24	26	28	28	21	26	30	25	25.6

Table 2. Data for Simulation Model (Required Level)

Parts	**No. of parts to be produced**	**Lead Time**
Part 1	21250	175 Hours (One month)
Part 2	20000	
Part 3	13750	
Part 4	16500	

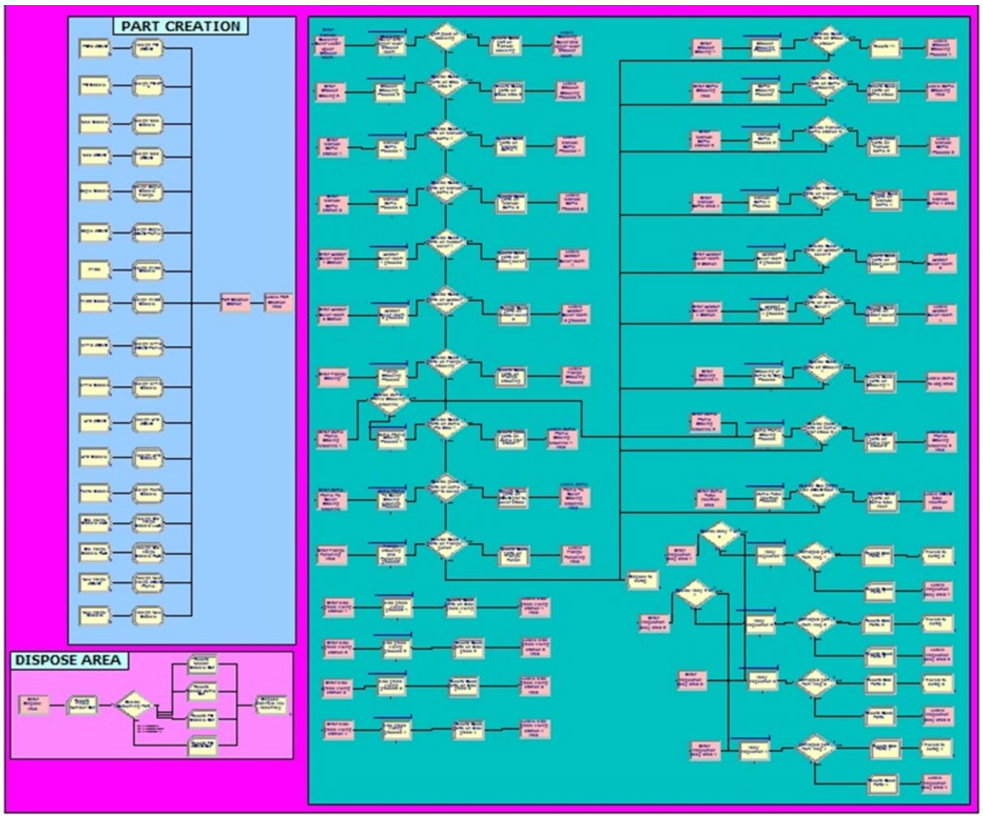

Figure 1. Simulation Model of Velocity Ltd.

4. Results and Discussion

A total of four scenarios are created. The expert from the firm suggested that the issues associated with worker absenteeism, resource breakdowns, and material shortages can be effectively addressed when the resource utilization ranges from 50% to 80% and thereby maintains a steady flow of production. In this study, the utilization range is termed as the utilization band. Thus, any resource having utilization > 80% is considered as a bottleneck resource for the firm under study. As explained earlier, a resource reallocation strategy is adopted to remove the bottleneck resource. So, the duplicate resources are identified for the bottleneck resource and the production load of the bottleneck resource is shifted to the duplicate resource. Further, the results from different scenarios are briefly discussed below.

4.1 Scenario 1

Scenario 1 captures the status of the firm without any TOC approach. It can be seen from Figure 2 that the resource utilization band ranges from 9% to 99.99%. Further, the throughput achieved in scenario 1 is lesser than the required level in the given period as shown in Table 3 and thereby resulting in late delivery.

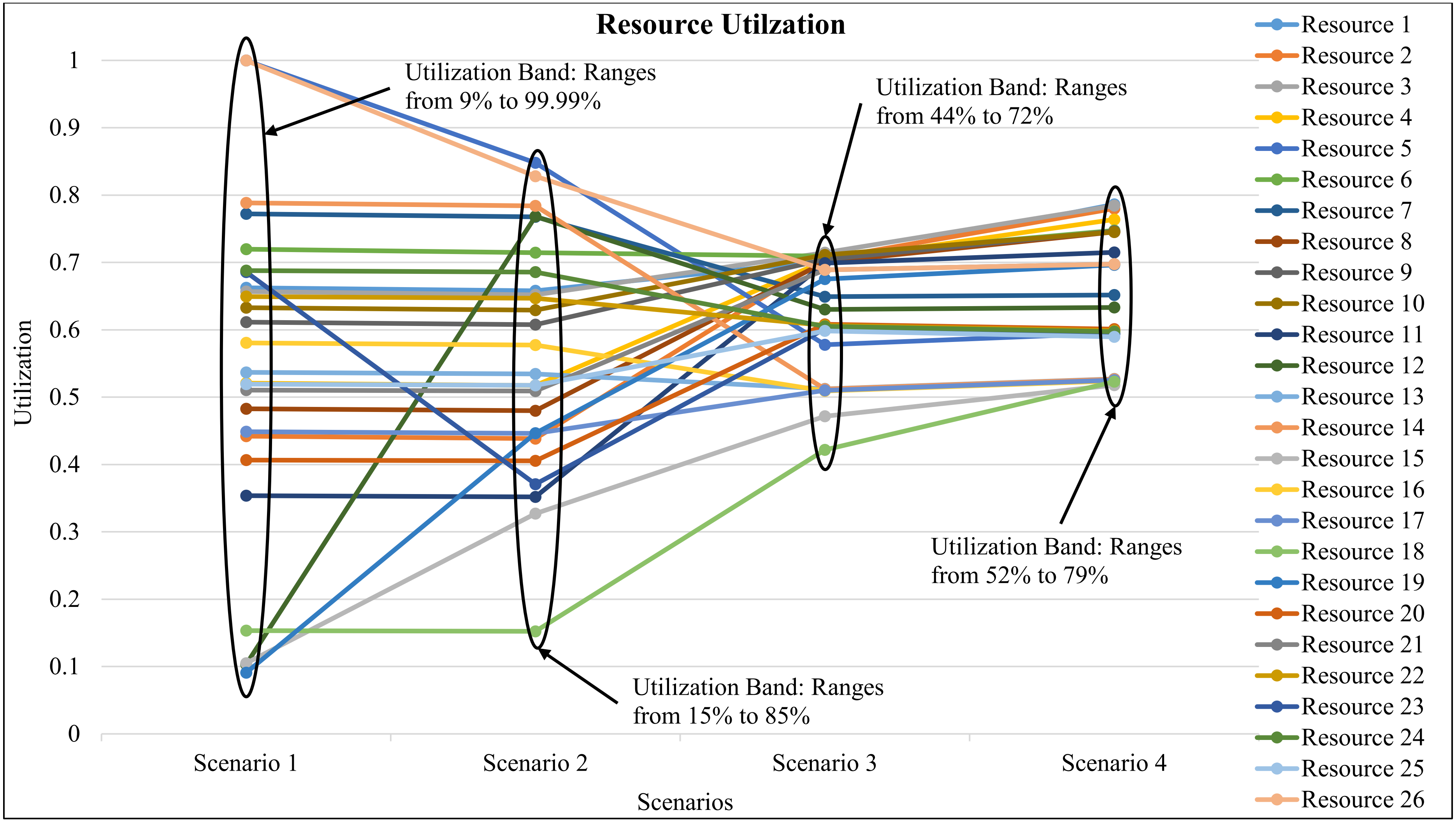

Figure 1. Utilization of Resources

4.2 Scenario 2

In scenario 2, the production load on the resources having utilization more than 80% i.e., bottleneck resources, is shifted to their duplicate resource. This resulted in compressing the utilization band to 15% to 85%, as shown in Figure 2. Also, there are few resources with utilization > 80%. Further from Table 3, it can be seen that the required level of the demand for parts is not fulfilled. Thus, again the same step is followed as scenario 1 to remove the bottlenecked resources.

Table 3. Simulation Results for Throughput and Lead Time

Scenarios	Throughput				Scheduled Run Length (hrs.)	Actual Time to produce parts (Lead Time) (hrs.)
	Part 1	Part 2	Part 3	Part 4		
Scenario 1	13734	12905	11321	11693	175	175
Scenario 2	15215	14742	12401	14735	175	175
Scenario 3	20252	17474	13354	16371	175	175
Scenario 4	21256	20073	13789	16627	175	167.42

4.3 Scenario 3

From Figure 2, the results obtained in simulation scenario 3 depict that the utilization band is further compressed and ranges from 44% to 72%. Despite, no bottleneck is observed, the required level of customer demand remains unsatisfied (see Table 3). The possible reason for this can be an underutilization of few resources. As the production manager suggested to maintain the utilization band of 50% to 80%, some resources are found to have utilization < 50%. Thus, the load of the resources with higher utilization is reallocated further to create scenario 4.

4.4 Scenario 4

In this scenario, the utilization band is observed to range from 52% to 79%, i.e., the suggested range by the expert (See Figure 2). Also, the demanded level of parts (throughput) can be produced in this scenario with-in the required lead time (167.42 hours), as shown in Table 3.

5. Research Implications

Applications of TOC to remove the bottlenecks have received immense attention from researchers and practitioners worldwide. Most of the researchers have demonstrated the implication of TOC strategies through the demo of hypothetical cases (Ikeziri *et al.*, 2019). A hypothetical case is an ideal scenario where the manufacturing constraint is known to the researchers or practitioners (Gupta *et al.*, 2002). However, in actual situations, the constraint is unknown and gets shifted after every constraint removal. Thus, the actual case scenario has a complex nature than the hypothetical. Therefore, the present study is a novel contribution to the body of knowledge on TOC literature to illustrate the implementation of TOC strategy for removing and exploiting the manufacturing constraints in an actual case to highlight the applicability of TOC in real situations. Further, the proposed TOC strategy i.e. reallocation strategy of TOC can be effectively utilized for redistributing the load of constraint or CCR resource over the underutilized duplicate resources. The policymakers or practitioners can adopt the proposed DES-based reallocation TOC strategy at a manufacturing firm for the successful removal of resource constraints.

6. Conclusion

The bottleneck management concept is emerged out of the TOC approach (Daultani *et al.*, 2015). TOC has a fruitful application since its inception in 1980. TOC consists of different strategies for elevating/exposing the capacity or availability of the bottlenecked resources. This study successfully demonstrated the use of reallocation/redistribution strategy of TOC in the actual case to enhance the manufacturing performances for fulfilling the customer wants using the simulation method. Shifting a load of CCR on the duplicate resources resulted in maintaining the resource utilization within the range and thereby helps to achieve the required throughput level within the stated lead time. Thus, the proposed strategy can be further utilized by researchers and practitioners for bottleneck management in the manufacturing firm. The proposed versatile TOC strategy can further be extended in the fields viz. Project management, supply chain, healthcare, marketing, accounting, and logistics.

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