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Application of TOC for a Newly Developed Shipbuilding Industry

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Abstract. The development of production technologies has been very influential in promoting economic growth, inducing changes in both social life and culture. The first wave of technology was organized by the agriculture revolution 15,000 years ago, and the second wave came with the industrial revolution started in Britain in the 17th and 18th centuries. In the more recent era, a third wave has undoubtedly been triggered by the advances with development of IT (Information Technology). Moreover, IoT (Internet of Things) will now trigger major technological innovation and shape the face of the industry. But when looking over the world, stagnation of industrial growth can be locally seen in various industry domains. The Theory of Constraints (TOC) may prove useful in examining main causes and mechanism of this phenomenon, and induce some paradigm shifts in the system. But unfortunately, there is no case of applying TOC for innovating shipbuilding. In this paper, the logics of growth and stagnation pertaining to the shipbuilding industry are extracted by applying the "TOC Thinking Process," The core dilemma restraining industrial development in that industry is clarified and resolved by this process. Furthermore, the effectiveness of the solution is verified by constructing a brief, random simulation model applied to the ship design stage in the upper-level process of shipbuilding, and the ship production stage within the lower process.

Keywords. TOC, Thinking Process, TPS, Throughput accounting, Shipbuilding

Introduction

The theory of constraints, which is called TOC for short, is renown for being a useful methodology to solve industrial production issues. TOC is based on the concept that the undesirable effects observed in the system are likely produced by certain core dilemma or conflicts. It views any manageable system as being limited in achieving more of its goals by a very small number of constraints [1][2]. The thinking process of TOC provides a simple method of finding and resolving such core dilemmas in particular, enabling the system to grow holistically in a significantly shorter time than ever before.

The production issue has been faced by Japanese shipbuilding industries for a decade. History has shown that there are core dilemma like the existence of diametrically opposed good ideas: "produce as much as possible" versus "not produce as much as possible.". Even though the declining completion trend in Japanese

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shipyards is influenced by world economic conditions, there are certain reasons why such problems must have been triggered within those organizations.

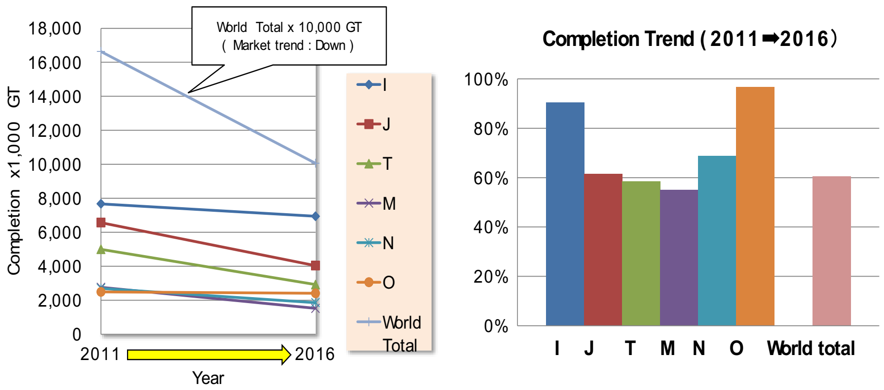


Figure 1. Completion trends of major Japanese shipyards (2011–2016).

Working off this assumption, this paper shall clarify an approach to search out the core dilemma of shipyards by digging into undesirebale effects and speculating about the causes of each one, followed by a deeper examination into the core dilemma itself.

The company is always chasing profits without exemption by various methods. But, some companies might fail to make a profit, thus facing the risks of employment. An unprofitable company generates quite a serious social issue. Goldratt & Cox (YEAR) presented a rapid-recovery methodology for a company's financial condition with simple and holistic improvement mechanism [2], which requires no additional investment. So, finding a way to apply TOC to the Japanese shipbuilding industry is worthwhile, especially since they represent (currently) one-fifth of the world's share of ships built and had held first place for 44 years (1956–1999).

1. The current condition of Japanese shipbuilding

1.1. Management logic to create biporarization

Figure 1 shows the production trends of major Japanese shipbuilding companies from 2011 to 2016. The name of companies are expressed by letters "I," "J," "T," "M","N," and "O." The total amount of production for the industry decreased by 60%, due to lower demand caused by poor global maritime economy conditions. However, companies "I" and "O" maintained high completion tendencies, with the same level of production. When these six companies were clustered based on high and low completion trends, two different management logics were found to exist under bad economic conditions. Plausibly, these managerial logics have had a direct impact on the overall performance of those companies. When considering the decision to produce as explained in the introduction, these two managerial paradigms may be depicted well by using the TOC thinking process (Figure 2). One logic is to increase production, the other, not to.

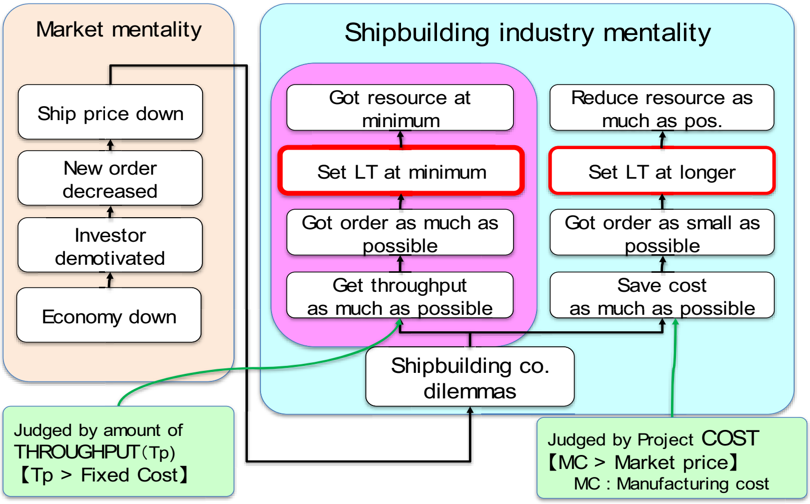


Figure 2. Two different managerial logics under poor economic conditions.

1.2. Bullet lists and enumerations

An early hypothesis that can be derived from Figure 2 is that companies act based on the merits induced by the amount of throughput or total project costs, in which both logics boil down to enhancing the company's profit. Referring to this hypothesis, two different actions were induced by each assumption: one by evaluating the amount of throughput, and the other by evaluating the manufacturing cost. Congruently, one might necessarily study which evaluation measure is most reasonable for improving profit. Mathematically, profit can be expressed as

$$P = S - C_v - C_f \tag{1}$$

$$P = T_p - C_f \tag{2}$$

Where,

P	:	Profit	S	:	Sales (Cash in)
C_v	:	Variable cost (Cash out)	C_f	:	Fixed cost
T_p	:	Throughput			

Since profit were dependent of time, differentiating equation 2 in time will produce.

$$\frac{d}{dt}P = \frac{d}{dt}T_p - \frac{d}{dt}C_f \tag{3}$$

Considering that a steady, profitable condition will have a positive speed of profit velocity that will produce the following boundary condition:

$$\frac{d}{dt}T_p > \frac{d}{dt}C_f \tag{4}$$

Equation 4 expresses that in order to improve profit, the throughput velocity must be increased more than fixed costs consume velocity. This reasonable logic can be seen in Figure 2, the logic to increase production. The other logic, not to increase production, determines to decrease fixed cost velocity, requiring a net reduction of resources, which in turn often triggers a social employment problem.

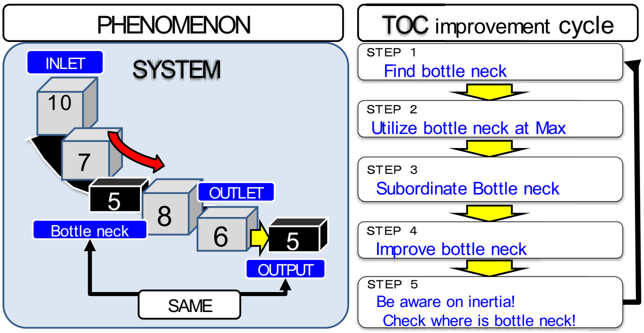


Figure 3. Two different managerial logics under poor economic conditions.

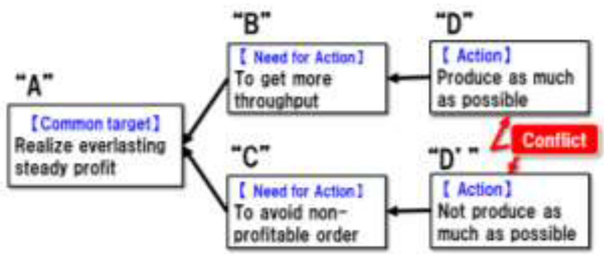


Figure 4. Dilemma of management.

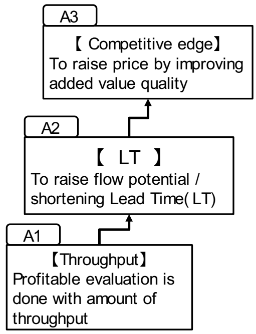


Figure 5. Linkage of solutions

2. Innovating a shipbuilding strategy with TOC

2.1. TOC improvement process and method to arrive at a solution

TOC explains that the output of a system is determined by its weakest stage, which is called the "bottleneck." The continuous improvement cycle focuses on the bottleneck, as shown in Figure 3. The production phenomenon involving the bottleneck during production is depicted by the left hand side of Figure 3, where the amount of outlay in every sub-process in the system fluctuates due to its own full-blown activity. As the example shows, only half the amount of inputs are successfully converted to output in the end process. In that case, the most interesting phenomenon shows that the amount of output produced at the bottle neck phase is the same as the end output of the system.

Figure 4 shows a conflict structure or CLOUD with two opposite actions as shown in Figure 2. The TOC thinking process provides quite a simple method for resolving dilemmas by making the following simple questions and answers as shown by Figure 5.

Q1. Is there any good way to satisfy both "B" and "C" at the same time?

A1. Profitable evaluation is accomplished with the right amount of throughput.

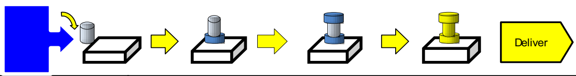
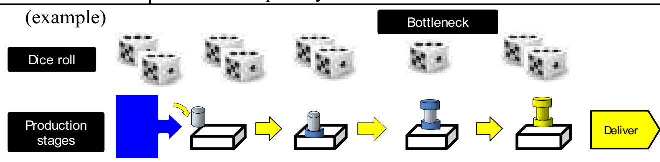
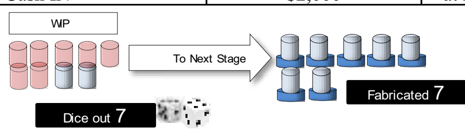
Q2. Is there any good way to satisfy "C" while doing "D"?

A2. To raise flow potential or shorten lead time (LT)

Q3. Is there any good way to satisfy "B" while doing "D"?

A3. To raise prices while improving value-added quality.

Table 1. Flow of dice simulation model.

No	Items		Description	
1	Linkage			
	Injection ➡ Stage A ➡ Stage B ➡ Stage C ➡ Stage D ➡ Deliver 			
2	Fluctuation of proceeding	By DICE roll => Create Random Number that express daily production capability (Dice expectation value is 3.5)		
3	Bottle neck	Set Dice quantity at minimum		
	(example)  Injection ➡ Stage A ➡ Stage B ➡ Stage C ➡ Stage D ➡ Deliver			
4	Cash flow		Amount	When
		Cash OUT	$1,000	at Injection
		Cash IN	$2,000	at Delivery
5	Modeling of Production Process			

2.2. Effectiveness of scenarios seen by dice simulation

To understand the TOC improvement logic interractively, one must study how to recover a company's financial condition by a simulation game introduced in Cox, et al. (YEAR) [4]. The simulation was done based on following two important company activity assumptions, i.e., (1) the system has certain linkages, and (2) fluctuations will occur going forward. The second assumption is quite unique and important. The fluctuations encountered going forward are quite undesirable when considering due dates simulated schedules, rendering somewhat less effective an estimation or schedule simulator for a due date, determined within a certain assumed tact time (which has to be longer than the minimum tact time). That fact means that it is quite difficult to shorten lead time. So, the second assumption may be expressed by rolling a dice, creating an interesting simulation method. The simulation model with these two assumptions is illustrated by Table 1. An example is taken from the fabrication of screws from injection to their delivery involving four intermediate stages. The random output for each stages is represented by the output value from the roll of two dices, expressing the daily capability at each stage. Hence, there will be a probability of 1/6 x 1/6 for every number to show after the dice roll. At this point, the bottleneck is defined as the stage that has the lowest value roll. In the example, the bottle neck is at stage C with dice value being equal to three.

Table 2 shows the target system based on one month of production, consisting of 20 working days' operations and system data. The target output and throughput are noted, as well as intial work-in-process (WIP), such as items that were either just being fabricated or were waiting for further processing in a queue or a buffer storage was set up. From the viewpoint of LT & profit, WIP must be minimized. However, if WIP is too small, the full power of bottleneck output cannot be realized, meaning that the firm will lose the opportunity to produce.

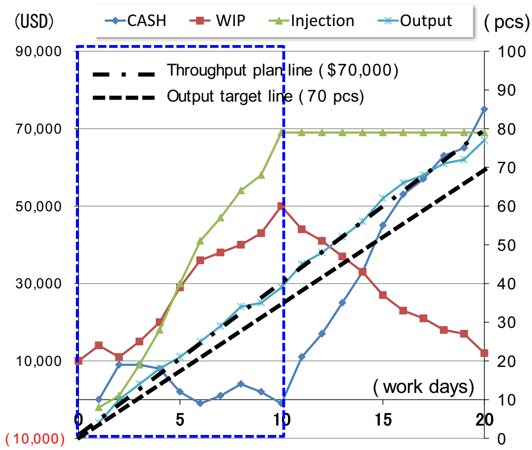


Figure 6. Dice simulation results: (Trends of cash, WIP, inputs and outputs).

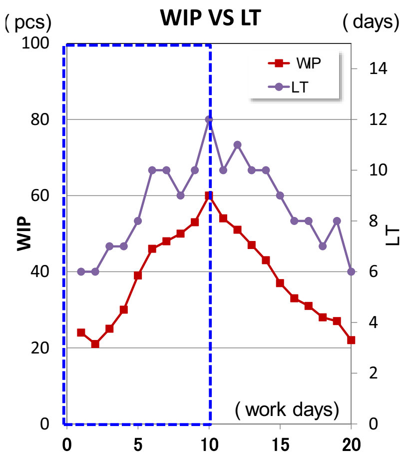


Figure 7. Dice simulation results: (Trends of lead yime & WIP).

Table 2. Monthly target of production and imput data for simulation

No.	Items	Value	Description
1	Target Output	70 pcs.	3.5 pcs./day x 20 days
2	Target throughput	70,000USD	(2,000 -1,000) USD/pcs.x 70 pcs.
3	Initial WIP at each stage		Stage "C" : 8 pcs., Other: 4 pcs.
4	Num. of dices		Stage "C" :1 unit (for bottle neck), Others: 2 units

Table 3. Producition results after one-half month operation

No.	Items	Result	Target	Evaluation
1	Output	39 pcs.	35 pcs./half month (70 pcs./month x1/2 month)	Good
2	WIP	60 pcs.	Initial condition : 20 pcs.	Bad
3	Throughput	-1,000 USD	35,000 USD(70,000USD/2)	Terrible

Thus, preparing adequately the firm's WIP for possible bottlenecks is important. This WIP also functions as a buffer. In non-bottleneck stages (A, B and D) there are four initial WIPs/stages while the bottleneck stage "C" has eight WIPs. To simulate the bottleneck, the number of dice to roll in the bottleneck stage is set to one, while in other stages it is set to two dice. Doing so results in making a queue of pre-fabricated material before the bottleneck stage that has a lower maximum daily production capability than during the other stages.

Figure 6 shows the dice simulation results. Up to the middle of month, all stages performed their best and all raw materials were injected to the system. However, WIP tended to decrease for the remaining working days. Up to this point, management review was required to discover necessary countermeasures in order to achieve the monthly target.

Data for ten days of production activity are shown in Table 3. The actual output shows a good result compared to the initial target. However, an extra four pieces can be seen there, having lower actual throughput compared to the half-month target.

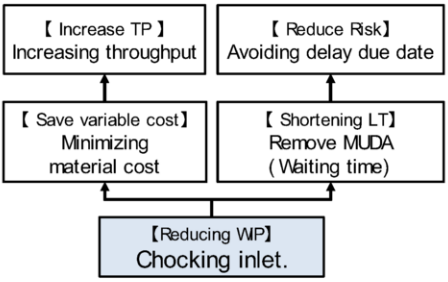


Figure 8. Tree diagram of probablility due to choking off injection of material at the inlet of a production system.

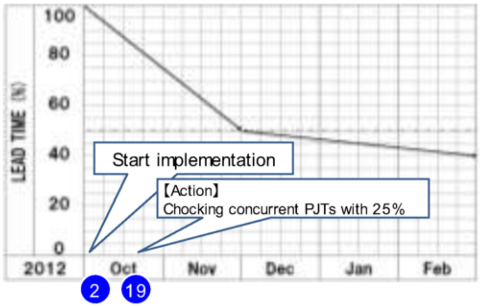


Figure 9. Implementing the TOC into the design stage.

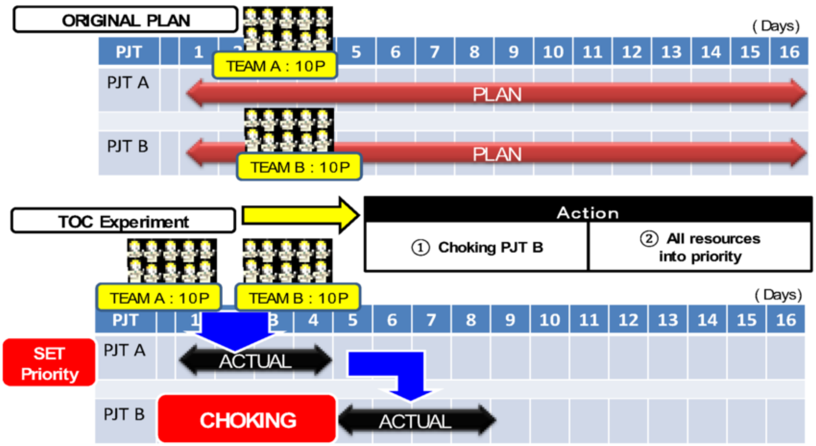


Figure 10. Results of introducing the TOC trial experiment into production sites in an Indonesian shipyard.

It must be understood that increasing WIP induced a decrease in throughput. As a countermeasure, management decided to reduce WIP by choking off inputs. This countermeasure brought the mitigating results shown in Figure 6. At month end, 77 pieces were produced, equaling the sum of the bottleneck (75) plus the stage "D" initial WIP (4) less the WIP of the prior stage on the last day (2), with throughput of 75,000 USD.

Another insight from the production process is provided by Figure 7, showing the relationship between WIP and lead time(LT). WIP and LT trends were found to have developed hand-in-hand during the production. Shortening LT reduces the serious risk of delay of given due dates. This hypothesis is depicted by Figure 8, showing the future reality tree after the choking process had started.

2.3. The trial experiment of TOC solution and its advantage

The simulation reported in the previous section showed that it is quite important to control the injection of material at the input stage, even by choking injection into production system at the initial production stage. Therefore, it is necessary to implement TOC as early as possible in the design stage of the shipbuilding process. Figure 9 shows the timeline of TOC implementation into the design stage. The choking off of injection was done by reducing 25% of concurrent projects. After three months, the company began to realize about 50% of LT.

Furthermore, an application of a TOC solution was implemented in an Indonesian shipyard. This experiment was conducted to verify the aforementioned concept ("to focus") utilizing the same quantity of resources and fixed costs (FC). Figure 10 shows the results from the trial experiment after taking a choking off measure reducing 50% injection of new tasks at the inlet point by introducing a concurrent job method in the production stages at this shipyard. In the original plan, two teams consisting of ten men apiece were assigned to two separate projects that ran simultaneously, each one using the same block construction. The original expected project LT was sixteen days each. By implementing TOC, the management decided to focus the resources at one project such that they became a priority before moving on to another one. The end result was reduction on the lead time (LT) by up to one-third of one day over the original plan, thus shortening the total production schedule. Furthermore, manpower utilization of was two-thirds more efficient than the original plan expected without any additional investment. The success of the experiment and from partially implementing TOC into shipbuilding systems showed that there is a good possibility that TOC may increase production capability in the shipbuilding industry when implemented.

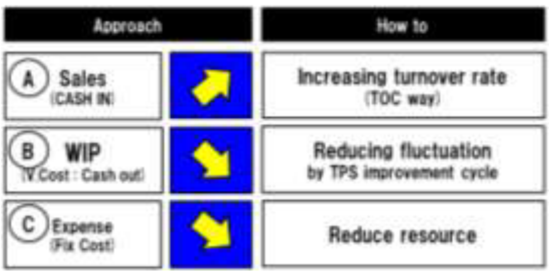


Figure 11. Three reforming measures to increase profitability.

Table 4. Comparison of study scenarios.

method	S1		S2	S3	S4	S5
(A) TOC method	Deviation of capacity	Nos of Dice [Case A] B.N. - Other 1 1.2	Improve bottle neck (Increase stage C's efficiency			
			Inlet=>1 Same as stage C	Improve bottle neck		
				Stage C 1=> 1.05	Stage C 1=> 1.10	Stage C 1=> 1.15
(B) TPS method		[Case B] 1 1.4	Decrease deviation of DICE			
			Min ⇔ Max 1 – 6	Min⇔Max 2 – 5	Min⇔Max 3 – 4	Min⇔Max 3.4–3.6
(C) Cost down		[Case C] 1 2 B.N .: Bottle neck (Stage C)	Reduce resources (Cut buffer			
			Cut stage D => 1	Cut stage B => 1	Cut stage A => 1	Cut Inlet => 1

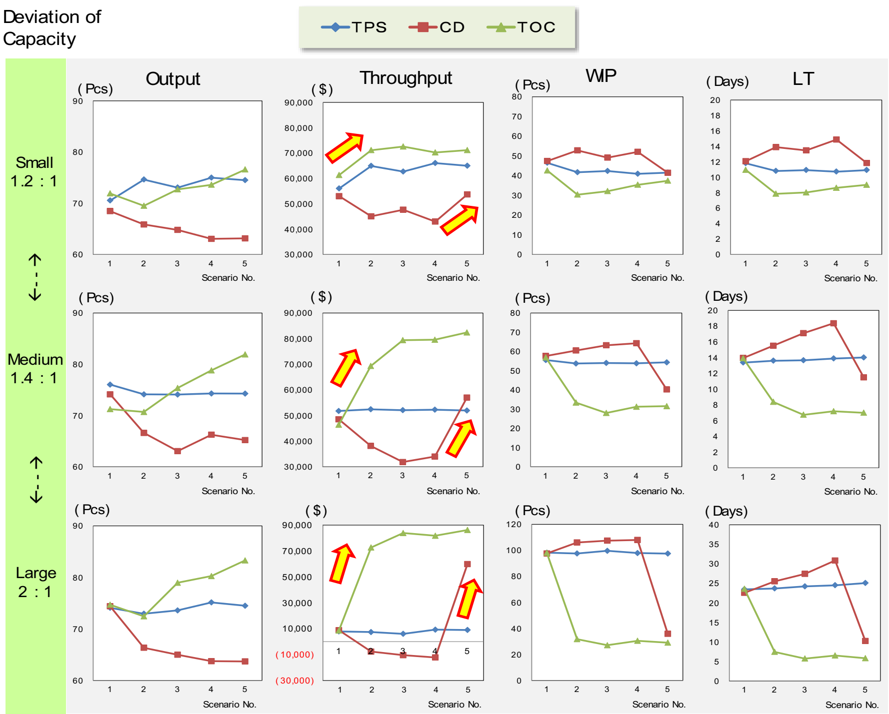


Figure 12. Comparison study of three methods to increase profitability by dice simulation.

3. Further learning using a TOC simulation

The effectiveness of TOC has been tested and examined by two cases in the previous section. Looking at the big picture, the simplest summary statement is that TOC is a means of improving ways to increase profit. Figure 12 shows a model comparison study for three methods to improve productivity. Table 1 shows a similar modeling concept to compare the three ways, utilizing random rolls of the dice by Cox, et al., (YEAR) [4]. The results may be translated into the "How to improve" aspects from the model:

Aspect 1) Increase the turnover rate: Realized by increasing the bottleneck capacity.
Aspect 2) Reduce fluctuation: Realized by reducing the deviation of dice number thrown.
Aspect 3) Reduce resources used: Realized by reducing number of dice used per roll.

Table 4 shows several model scenarios for the comparison. In line with the example provided in Table 1, the bottleneck area is set as Stage "C." There are five scenarios examined for each method "A," "B" and "C." A variable was set to differ from each scenario to another to depict the situational deviation. For method "A," the number of dice(capacity) in the bottleneck area varies. For method "B," the deviation range of the dice that represent the stage's output varies. For method "C," a production stage is being cut to represent a reduction of the resources due to a management policy. Figure 13 shows the average result after twenty simulation runs for each scenario and each capacity deviation. The following result can be summarized interpreting the figures:

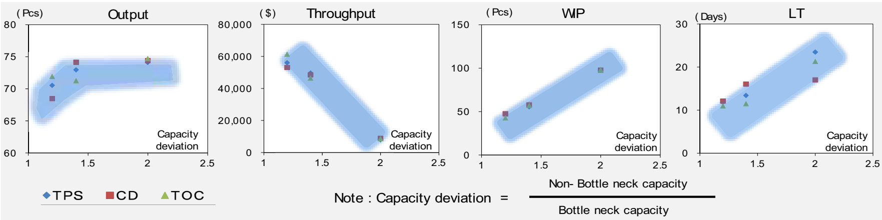


Figure 13. Varied results corresponding to capacity deviations.

1. The TOC method brought significant positive results by increasing the amount of throughput using a choking off of the inputs. Reducing WIP by input choking realized a significantly shorter LT, which reduced the risk of delaying the due date and increasing throughput.
2. The TOC method always resulted in an increase in throughput for all scenarios compared to any other method, showing its effectiveness and flexibility to input variable changes.
3. No significant results could be seen that lessened fluctuations by the TPS method.
4. The cost-down method reduced total throughput concurrently with no signnificant profit improvement.

Moreover, Figure 13 shows that results other than output vary on the deviation of each stage's capacity. On the one hand, in both the TPS and cost-down (CD) approach, larger capacity deviations were seen to bring smaller throughput, more WIP and contributed to longer LTs. On the other hand, the TOC improvement approach was able to resolve this problem simply by choking off inputs.

4. Conclusion

This paper investigated a core problem seen in the variation of Japanese shipbuilding production under poor economic conditions by implementing the theory of constraints to find core dilemma and propose reform measures to improve work processes and shorten project lead times. Based on the simulation results, the following conclusions were obtained:

1. There is dilemma "to produce more or to produce less" under poor economy conditions for Japanese shipyards.
2. The solution to eliminate the dilemma is to increase throughput by reducing work-in-process.
3. Choking off input control is the most effective to reduce work-in-process and to increase throughput.
4. The theory of constraints is well-suited for the shipbuilding industry
5. The theory of constraints approach is quite fast and simple to implement compared with other improvement methods such as TPS and cost down

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