Model to Implement Theory of Constraint in Sea Transportation System

Mulyono[1], Dian Prama Irfani[1]
[1]Universitas Pertamina, Indonesia

Keywords: Sea transportation system, Analytical Hierarchy Process

Abstract: Given the important role of sea transport costs, many researchers have made several efforts to increase the productivity of sea transportation system. Nevertheless, litreature review suggests that many optimization efforts that have been carried out so far are still limited to the local aspect of the system. This study aims to develop and implement a method to identify and manage constraints of the sea transportation system to help decision makers in increasing global productivity of such system. This study uses a combination of case study and computer based simulation methods. Case study is carried out on a sea transportation system in a company that engaged in the field of oil and gas. The developed constraint identification method can be applied to the case company, so that it is known that the main constraint of the sea transportation cost in the case company is the jetty capacity. This research contributes to stakeholders in the field of transportation systems to identify system's components that hamper global system performance. This research can be expanded by replicating the proposed method to the context of other sea transportation systems to test the generalizability of the proposed method.

1 INTRODUCTION

Since the impact of sea transportation costs on macro and microeconomic growth is huge (Limao and Venables, 2000), some researchers are interested in finding new ways to increase the productivity and efficiency of the sea transportation systems. However, even though there have been many researches conducted to improve the efficiency of the sea transportation system, most of the existing researches are still done partially. When conducted partially, optimization activities of the components of the marine transportation system tend to result in local optimum solutions. For example, an optimization aimed at increasing the speed and carrying capacity of a ship is largely based on the assumption that the speed and capacity of the transport in the future can be utilized to its maximum capacity. Fast ships with large capacity will indeed have higher transport productivity compared with slower ships with smaller capacity. Nevertheless, in practice the speed and capacity of the ship's transport may not be able to be utilized to its maximum point given that in the real system there are several limitations such as port drafts, crowded shipment lines and so forth, which inhibit ships from being able to sail at maximum speed and loaded in accordance with its transport capacity. The existences of several factors in the system that limit the utilization level ultimately contribute to limiting transport productivity and efficiency. In this case, number of studies aimed at optimizing sea transportation costs by reviewing ships, management, and infrastructure as a holistic system is still limited.

In addition to the scope of optimization, several studies that have been carried out mostly focus on the short-term time horizon. If the focus of the improvement is only on the short term horizon, the resulting solution can be not optimal for the parties concerned with the system. When the capacity of a system component which is seen as a given factor has been utilized to the maximum point, efforts to increase efficiency can no longer be done.

In terms of the dimensions, most of the efforts to improve system efficiency that has been carried out have not aligned the strategic, tactical, and operational dimensions as an integrated performance measure. In this case, improvement that is only conducted at operational level does not necessarily produce the best solution for the system.

In order to be effective, efforts to improve system efficiency need to be conducted by considering all the factors that make up the marine

Mulyono, . and Irfani, D.
Model to Implement Theory of Constraint in Sea Transportation System.
DOI: 10.5220/0008373700430049
In *Proceedings of the 6th International Seminar on Ocean and Coastal Engineering, Environmental and Natural Disaster Management (ISOCEEN 2018)*, pages 43-49
ISBN: 978-989-758-455-8

transportation system as a whole, long-term oriented, and aligned from the operational to the strategic levels. Improvement activities must focus on the factors that become the main constraints of the system.

One concept that can be implemented is to use a system thinking approach. In this case, Theory of Constraint (TOC) is a methodology used to implement systems thinking concepts. TOC is one of the multi facet methodologies developed to help organizations analyze problems and develop solutions to solve problems (Mabin and Balderstone, 2000). TOC is based on the principle that the performance of a system is limited by a constraint. Improving the performance of the system's constraints will have a direct impact on the performance holistically. Based on this principle, efforts to improve performance are focused on identifying and managing the constraints of the system.

The concept of managing the performance in the TOC is in line with the challenges faced by decision makers in the context of the marine transportation system. Firstly, efforts to improve the performance of TOC-based systems involve analysing overall system. The constraint identification activity which is one of the stages in the TOC involves efforts to identify the profile and relationship of each system component and its effect on the performance of the overall system. Secondly, the constraint handling framework in the TOC provides guidelines for formulating optimal solutions for the short and long term. Thirdly, TOC can be used to formulate and bridge strategic solutions with operational solutions. TOC provides a stage that is focused on formulating performance measures at the strategic, tactical and operational dimensions.

Although has been widely implemented in the manufacturing sector, currently TOC is not that popular in the field of sea transportation services. In this case, TOC implementation in sea transportation service is still very limited. The concept of constraint identification and constraint management is still vague. Litreature suggests that there is no operational guide on how to implement TOC concept in the field of sea transportation context.

Based on the aforementioned, this paper aims to develop a new method for implementing TOC concept in the context of the marine transportation system. The focus on research in this case is to:

1. Develop a new framework to operationalize the concepts and philosophy of the TOC in the context of the marine transportation system.
2. Develop a model of marine transportation system as a series of holistic systems.
3. Implement the developed framework into the case company to identify constraints in the marine transportation system.

2 LITREATURE REVIEW

Previously, Devanney et al. (1975) developed a computer-based model to determine the efficiency and inefficiency of several shipping activity scenarios. They assumed that port time for all shipping activities was the same. The assumption in this case limits the benefits and usefulness of the model developed (Lane, 1987). Meanwhile, Lane et al. (1987) conducted a study by developing a heuristic optimization model to schedule container ships on the north Atlantic route. The purpose of scheduling and using models is to optimize transport productivity which translates to increasing profitability and decreasing transit times.

Similarly, Perakis et al. (1991) developed a linear programming model to minimize operating costs from liner liners. Operational costs included are fuel costs, daily running costs, port charges, and canal fees. In a more detail, Laderman (1966) developed an optimization model aimed at minimizing the number of vessels needed to meet transportation demand. Rao and Zionts (1968) developed a linear model for assigning ships to certain trips to minimize operational costs by adding one variable to find out whether additional chartering activities are needed or not.

Based on the litreature review that has been carried out before, previous studies generally have the following limitations:

1. Performed on processes or components of the marine transportation system partially, so that the resulting solution is local optimum.
2. Focused on the short term based on the assumption that transportation demand and operational or infrastructure conditions are fixed over time. Although the efforts that have been made can have a positive influence on the optimization of operational costs in the short term, for the long term the impact of the implementation of these models is still a question mark, especially if transportation demand and operational conditions change.
3. The performance targets of optimization activities tend to focus on operational aspects, so that the alignment with the achievement of strategic performance criteria is not known with certainty

When compared with previous studies, this research has several differences. This research integrates components of a sea transportation system holistically, which in this case includes transportation equipment, management systems, and infrastructure. In addition, this study also focused on short and long term time horizons. Furthermore, this study includes operational and strategic layers performance measures. The output of the research is focused on producing effective and efficient global solutions. Position of this research can be seen in Table 1.

Table 1: Position of This Study Relative to Previous Researches.

Item Covered	Research						
	[3]	[5]	[6]	[7]	[8]	[9]	Proposed Research
Vessel	√	√	√	√	√		√
Management system							√
Infrastructure						√	√
Sort term oriented solution	√	√	√	√	√	√	√
Long term oriented solution							√
Operational performance	√	√	√	√	√	√	√
Global performance							√
Efficiency focus	√	√	√	√	√	√	√
Effectivity focus							√

3 METHODOLOGY

TOC provides five focusing steps to guide practitioners in improving system's performance. The TOC implementation stages in the five focusing steps are as follows:

1. Identify constraints
2. Exploitation constraints
3. Management of system flow that passes through constraints
4. Increased constraint capacity
5. After the constraint is eliminated, return to step 1.

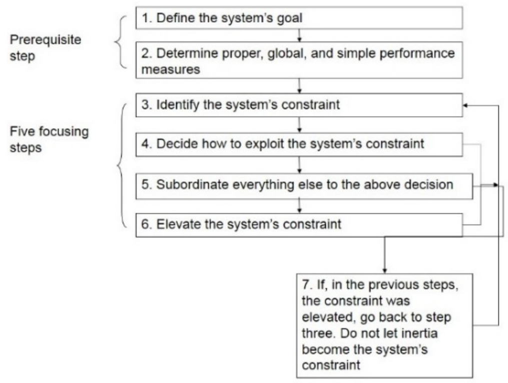

Figure 1: The Process of Ongoing Improvement (Goldratt, 1986)

The five focusing steps then evolved into the Process of Ongoing Improvement (POOGI). POOGI is basically the five focusing steps that are added with two pre-requisite steps, namely defining system goals and determining performance measures. In general, the steps contained in POOGI can be seen in Figure 1.

The explanation of each step contained in POOGI is as follows:

1. Step 1: Define the system's goal

Defining the purpose of the system depends on the purpose of the system. Goldratt (1986) explained that the purpose of the system must represent why a system exists.

2. Step 2: Determine global performance measures

Goldratt (1986) explain that global performance measures serve to translate the goals of the system into measurable units.

3. Step 3: Identify the Constraint

Constraint identification activity means identifying elements or factors that limit system performance improvement related to the achievement of system objectives.

4. Step 4: Exploit the Constraint

Constraint exploitation is an activity carried out to optimize existing resources, so that the performance of the constraint can be maximized.

5. Step 5: Subordinate Everything Else

Non-constraint resources must be managed so that constraints can be utilized until the optimal point at any time.

6. Step 6: Elevate the constraint

In (Groop, 2012), elevate the constraint means increasing the capacity of the constraint in order to increase the throughput of the overall system.

7. Step 7: If the constraint has been removed, go back to step three

After the constraint is successfully removed, the system must have another new constraint (Groop, 2012).

Because the method to implement TOC concepts in the field of marine transportation system is limited, this research aims to adapt, modify, and propose new tools that can be used to translate the general stages contained in the TOC into such system. The methodology will be built through the synthesis of some of the literatures. To find out the applicability of the TOC, the proposed methods will be applied to develop an improvement plan in one company that provides sea transportation services.

4 THE PROPOSED FRAMEWORK TO IMPLEMENT TOC IN MARINE TRANSPORTATION SYSTEM

The proposed framework to implement the TOC concept in the context of the marine transportation system is as follows:

1. Step 1: Define the system's goal

Interviews or focus group discussions to top executives who represent the role of the system owner are proposed to define the system's goal. Analytical Hierarchy Process (AHP) method is proposed to be used to select the system's goal.

2. Step 2: Determine global performance measures

TOC has four operational indicators called Throughput, Inventory, Operating Expense, and Productivity. In this study, those indicators are operationalized as follows:

a. Throughput is defined as the volume of cargo that is successfully transported in one unit of time or the amount of revenue generated from shipment services.

b. Inventory can be defined as a cargo loading space that is not or not yet utilized for a period of time. From the aspect of port infrastructure, inventory can be interpreted as converted monetary value of the jetty resource, loading and unloading device, and other equipment that is not yet or not yet efficient.

c. Operating Expense is the total costs incurred to change the ship's space and capacity of the port infrastructure to provide transportation services

d. Productivity in sea transport systems can be interpreted as the ratio between the volumes of cargo transported to the costs incurred to carry out cargo.

To prevent system optimization that focuses on the operational level, in this study global indicators at the strategic level are also proposed. Several indicators that can be used to measure strategic indicators of the sea transportation system are Net Profit, Net Present Value, and Return on Investment (ROI).

Step 3: Identify the System's Constraint

The proposed methods to identify constraints system are as follows:

1. Identify the main activities of the marine transportation system
2. Arrange the main activities of the marine transportation system into a series of transportation processes
3. Identify the resources used for each activity
4. Identify units or units of measures used by each resource
5. Convert different units of measures into one global unit of measures
6. Identify the maximum capacity of each resource currently available
7. Identify currently utilized resource capacity
8. Identify resources that causes bottlenecks on marine transportation systems by comparing utilization rates

Step 4 and 5: Exploit the System's Constraint and Subordinate Everything Else

To exploit constraints and do subordinate system's resources, the method that will be used in this study is to modify the existing system, especially in the scheduling pattern. Modification is done through an iterative system simulation.

Step 6: Elevate System's Constraint

Constraint elevation activity is related with investment activities. In this study, system's constraint elevation is proposed by using a simulation approach.

5 APPLICATION OF THE PROPOSED FRAMEWORK

5.1 Description of Company A

The sea transportation system that is used as a case is the transportation system in Company A, which is a company engaged in the oil and gas business both in the upstream and downstream sectors. Business in the upstream sector is carried out in several regions in Indonesia and abroad including activities in the fields of exploration, production and transmission of oil and gas. In the downstream sector, Company A's activities includes processing of crude oil, marketing and trading of oil, gas and petrochemical products.

5.2 Framework Implementation

To choose the goal of the marine transportation system in Company A, in this study interviews were conducted with management team. The process of determining the objectives of the system is carried out using the Analytical Hierarchy Process (AHP) method. After eigenvector-based normalization, consistency index calculation, and consistency ratio calculation, the final result of each goal shows that the selected goal of the marine transportation system in company A is to fulfil the shipment demand efficiently.

Performance measures that will be used to analyse the sea transportation system in Company A is shown in Table 2.

Table 2. Performance Measurement in Company A

Layer	Indicator	Formula	Measures
Operational	Throughput	Volume of cargo transported over a period of time	Kilo Litre
	Inventory	Converted monetary value of the ship space and port infrastructure that are not or not yet utilized for a period of time	IDR
	Operating Expense	The total costs incurred to change the ship's loading space and port infrastructure capacity for transporting cargo over a period of time	IDR
	Productivity Ratio	Comparison between volume of cargo transported to the costs to carry out cargo	Ratio
Strategic	Net Profit	Throughput - Operating Expense	IDR
	NPV	Sum of some present values for benefits obtained over a period of time	IDR
	ROI	Net Profit / Inventory	Ratio

Sea transportation system consists of several factors whose unit of measures are not standardized. To identify system's constraint, such measures need to be firstly standardized into common unit. In this research, the proposed unit for measuring capacity and utilization of each resource in the marine transportation system is the ratio between volumes of cargo handled over a period of time. In this case, Kilo Litre per day is suggested. Table 3 shows the utilization of several marine transportation resources in company A that is presented in the original and standardized units.

Table 3. Process Mapping and Unit of Measure Conversion

Process	Resources	Original Unit		Converted Unit	
		Value	Unit	Value	Unit
Sailing at Sea	Speed	11	Knots	18,400	KL/ Day
Steaming In	Draft	4.5	Meter	10,700	KL/ Day
Berthing	Jetty	2	Unit	2,000	KL/ Day
Clearance	Human Resource	12	Ships/ Day	50,400	KL/ Day
Laboratory Test	Human Resource	12	Ships/ Day	50,400	KL/ Day
Discharging	Pump and Pipe	400	CuM/ Hour	9,600	KL/ Day
Tank Inspection	Human Resource	8	Ships/ Day	33,600	KL/ Day
Document Processing	Human Resource	8	Ships/ Day	33,600	KL/ Day

The process map of the sea transportation system in Company A is shown in Figure 2.

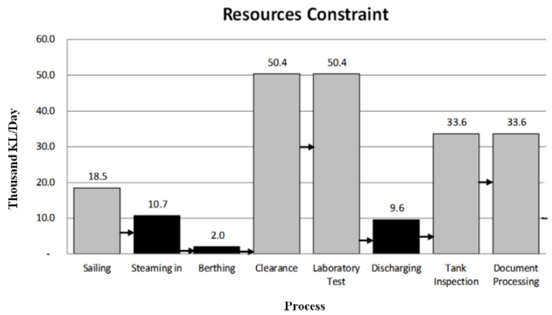

Figure 2: Result of Process Map Analysis to the Sea Transportation System in Company A

Based on the process map in Figure 2, it is known that jetty capacity in Company A is only able to handle 2,016 KL of cargo per day. Meanwhile, the cargo pump at Company A can only handle 9,600 KL of cargo / day. With a 4.5-meter port draft, the system at COMPANY A can only handle as much as 10,739 KL / Day. Therefore, based on the process map it can be seen that the main constraint that limit the performance of the marine transportation system at Company A is the jetty capacity.

Company A currently have two berths with the number of ship arrivals approximately 306 times in one year. Thus, the jetty occupancy rate is 88%. Based on the existing conditions, scheduling optimization simulations are carried out by rearranging ship arrivals with the objective function to maximize jetty utilization and meet the transportation demand at the port. Based on some simulation results, the steps in the TOC framework to exploit the constraints and subordinate system components to optimize jetty utilization produce a final solution where the idle jetty frequency is 5 times. The solution can reduce idle jetty. However, in terms of the congestion, the resulting solution is no better than the current scenario. The simulation results with the existing model show the frequency of congestion 7 times, while the optimization results actually produce 8 times the frequency of congestion. Based on this, it can be seen that the exploitation stage and subordinate system components are not effective to improve the system's performance.

To overcome the constraint, one of the steps proposed is to simulate the marginal return on investment if constraint elevation is carried out through investment activities. In this study, the evaluation of investment activities was carried out for two layers, namely the strategic layer and the operational layer. At the strategic layer, an evaluation of the jetty expansion simulation will be measured by a Net Present Value indicator of benefits obtained over a period of time. In this case, an investment in the form of jetty constraint expansion can be said to be feasible if the simulation results show that the investment activities carried out produce a positive Net Present Value.

Meanwhile, from the operational aspect, the evaluation of investment returns will be carried out by using the indicators of productivity of the sea transportation system. An investment in the form of jetty constraint expansion can be said to be feasible from the operational aspect if the simulation results show that the investment activities carried out have an impact on increasing the productivity of the sea transportation system. The simulation result of constraint elevation is shown in Table 4.

Table 4: Changes of Global Performance Measures after Constraint Elevation

Scenario	Description	Performance Measure	Value	Unit
Scenario 1	Capacity is increased by 50%	Throughput	1,026,602,448	Litre
		Operating Expense	64,378,970,945	IDR
		Productivity Ratio	0.0159	Litre/ IDR
		Inventory	1,583,540	Kilo Litre Day
Scenario 2	Capacity is increased by 100%	Throughput	1,026,602,448	Litre
		Operating Expense	65,273,219,692	IDR
		Productivity Ratio	0.0157	Litre/ IDR
		Inventory	2,266,158	Kilo Litre Day
Scenario 3	Capacity is increased by 150%	Throughput	1,026,602,448	Litre
		Operating Expense	66,873,219,692	IDR
		Productivity Ratio	0.0154	Litre/ IDR
		Inventory	2,992,184	Kilo Litre Day

Based on Table 4, it can be seen that scenario that provides the optimum return for Company A is the scenario of adding 1 jetty.

6 CONCLUSION

Based on the series of processes that have been carried out, several conclusions can be formulated as follows:

1. This study has successfully developed integrated framework to implement the concept of

TOC. Several existing managerial methods and tools like AHP, process map, and simulation tools have been incorporated in the TOC-based framework. In addition, this research has proposed a new method to identify the constraint of the marine transportation by converting unit of measures of each process in the system into one standardized unit. Additionally, performance indicators like throughput, operating expense, productivity ratio, and inventory have also been redefined and proposed to be used in the context of marine transportation system.

2. TOC-based model can be applied in the context of sea transportation systems, more specifically to help formulate performance measures, identify key constraints that limit the performance of the marine transportation system, and formulate strategic steps to improve the performance of the marine transportation system.

3. The developed method can be applied in the case company to formulate the objectives of the sea transportation system, define performance measures, identify constraints, and handle constraints

This research can be further enhanced by applying the developed methods on other transportation systems. In addition, statistical tests to determine the impact of formulated improvements can also be done.

REFERENCES

Goldratt, Eliyahu M. (1986): The Goal: a process of ongoing improvement, North River Press.

Groop, Johan (2012): Theory of Constraints in Field Service: Factors Limiting Productivity in Home Care Operations, Aalto University Publication Series, Helsinki.

Laderman, J., et al. (1966): Vessel Allocation by Linear Programming, Naval Research Quarterly, 12, 315 - 320.

Lane, D. E., et al. (1987): Planning and Scheduling for Efficiency in Liner Shipping, Maritime Policy and Management, 14, No. 2, 109 - 125.S. Boffey, J. Oper., 1979. Res. Soc, 30, 413 – 425.

Limao, Nuno dan Venables, J. Anthony (2000): Infrastructure, Geographical Disadvantage, and Transport Costs, Washington.

Mabin, J. Victoria dan Balderstone, J. Steven (2000): The World of the Theory of Constraints: a Review of the International Literature, St. Lucie Press, pp 11 – 12J. W. Devanney, J Trans, 1975. Econ. Policy, 9.

Perakis, A. N., and Jaramillo, D. L. (1991): Fleet Deployment Optimization for Liner Shipping, Maritime Policy & Management 18 (3), 183 – 200.

Rao, M. R., dan Zionts, S. (1968): Allocation of Transportation Units to Alternative Trips – A Column Generation Scheme with Out-of-Kilter Sub problems, Operation Research 16, 52 – 63.Ellis and C. Steven, 2011. Flor Inter.

Ronen, B., dan Spector Y. (1992): Managing System Constraints: A Cost/Utilization Approach, International Journal of Production Research, Vol. 30, No. 9, pp. 2045 - 2061.