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The Development of a Queuing Model for Optimization of Seaport Facilities at Tanjung Perak Seaport, Indonesia

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Abstract : *Optimization of sea-port facilities is one of the common problems encountered in the optimization of the harbor. In this study discusses the development of the queuing system for optimization of harbor facilities. Queuing system developed is a model queue with server service pattern that follows the Erlang distribution which consists of two phases of service and discipline priority queue preemptive resume. The process of developing the model was done using two approaches, with the approach of mathematical models and fuzzy models. Mathematical approach was taken to determine the queue statistics such as waiting times and long queues. For fuzzy model approach was done to facilitate the optimization process so that the optimization model is simplified. Simulation and analysis which has been obtained showing that the service system application server with Erlang distribution can improve the optimization of services provided so that the ship waiting time becomes shorter than the service model with an exponential distribution which has been used in the model approach.*

Keywords: *Erlang distribution, Fuzzy model, Queuing model, Poisson distribution, Sea-port.*

I. Introduction

Indonesia is a maritime country that most of its territory consists of islands and sea. Sea is a tool which holds important and strategic role in the development of the region, especially to support the activities of government and the economy, such as industry and trade. The need for port services that is productive, effective, and efficient, to be one factor accelerating the development of regions in Indonesia. To realize these desires, then the implementation of the national port activities should run well. This means that all the facilities available at the port should be used optimally both in quantity and value of its usefulness.

Many factors must be considered to determine whether a port is already operating optimally or not. Furthermore, it required a method to make an approach for optimizing existing facilities, such as docks and yard. Therefore, in this paper, the authors will describe the development of a harbor facility optimization method using fuzzy logic for complex queuing system.

In queuing theory, queuing models can be used to approximate the original queuing situation or system [1]. Therefore, the queuing behavior can be analyzed mathematically. Queue model enables various useful measures of performance stable conditions to be determined. Queue is an event that is common in everyday life. Queues often caused things are not desirable, because it can cause the time, cost, and other resources wasted. A queue can occur because the available server capacity cannot meet existing needs. Some of the factors that cause a server cannot meet the requirements, including the limitations of space and cost. Queues that occurred in the harbor are a queue that occurs because of a number of ships that will carry out the loading and unloading of goods. To be able to perform these activities, the ship must be moored at the pier first. Mooring capacity in the dock is usually very limited, so if the number of arrival of the vessel is greater than the level of service the ship at the dock there will be a queue of ships waiting their turn.

If the condition of the queue at the port is already quite dense, where the vessel time waiting a very long, then the manager of the port should implement a specific rule on the ships coming. There are some specific types of items that should be demolished because it is very important, such as staples and fuel oil. Their priority in the service will lead to increasingly complex queuing system. Some specific types of ships bound to experience longer delays than normal conditions.

Queuing theory expressed using mathematical tools aimed to describe the characteristics of a queuing system. Some things are taken into account in a queue, among others, the probability of the number of vessels in the system, the average queue length, average wait time, and others. The queuing system is a problem that is random and nonlinear. Queuing system which is expressed in a mathematical equation has the form of a very complex that only a simple queuing system that can be fully described by a mathematical model. To be able to describe a complex queuing system, we need a different approach methods are expected to be easier and simpler so that the optimization process will be easier to do.

Fuzzy logic is a method other approaches that can be used to take a decision. This method has actually been around a long time, but has developed rapidly since the last few years. Fuzzy logic method was first introduced by Lotfi A.Zadeh in 1965 [2]. The use of fuzzy logic has been widely applied in various fields of science because the concept can apply the experiences of experts directly without having to go through the training process. Furthermore, fuzzy logic can be used to model the nonlinear functions are very complex and have tolerance for data that is not appropriate.

Queuing system model boat at the dock that has so far is still expressed by a mathematical model that is complex. To perform optimization with a mathematical model would be more difficult. Although the optimization method by using mathematical models already undergone many developments and proven still widely used today, but it can be said that the results achieved have not been able to meet expectations because of the complex.

Some of the problems discussed above are the background to this study. Author used fuzzy logic to perform the optimization approaches in the dock facilities. The theory of fuzzy logic used in this study are the methods associated with how to control a queue system that is expressed in the form of fuzzy model of the queuing system for queuing ships in harbor. Furthermore, fuzzy queuing models will be used to determine the optimal capacity of the dock by considering the cost factor. Methods of optimization with fuzzy logic approach are expected to provide better results.

An issue of concern in this study is how the optimization method appropriate if the complex queuing models with different behavior of each server are applied at the port. Some harbor facilities optimization methods that have been developed at this time, is done by using queuing model approach with exponential service pattern with queuing discipline FCFS (First Come First Service) without priority. In this model every customer gets equal opportunity in getting services. But in reality the queue model is not fully in place at the port, because there are some certain types of goods that should get priority in service. This causes an optimization model for port facilities is less than optimal.

To increase the level of port optimization requires a more realistic model of the queue. The possibility of a service priority in the queuing system should be taken into account because it affects the performance of port services. One model queue that will be discussed in this study is a model queue multiple servers using a queue discipline LCFS (Last Come First Service) with priority service.

The optimization model is expressed in a mathematical form requires a complex calculation and iterating long enough. Therefore, the researchers used a fuzzy model to simplify the complex mathematical models that process optimization is not a difficult thing and the results can be obtained more quickly.

This paper aims to develop a methodology for the optimization of port facilities by using the concept of fuzzy logic in a complex queuing system and the behavior of each server is different. The application of a disciplined service and queue with priority queuing systems in service at the port is one of the factors into consideration, factors other than minimum total cost. This optimization model will be applied to the queuing system at the port. The discussion in this study did not take into consideration passenger pier, lodging and fishing pier. Another limitation associated with the queue model is that the ship does not have the freedom to determine which server will serve.

II. Theoretical Background

A. The Queuing Model

To illustrate a queue system required some basic components, namely:

1. The stochastic process that describes the pattern of arrival of the vessel (A)
2. The stochastic process which describes the pattern of service server (B)
3. The number of servers (m)
4. The capacity of the system (K)
5. The population size vessels (N)
6. Discipline queue or queue management (Z)

A queuing system can be described with the notation Kendall *A/B/m/K/N/Z* where *A* and *B* are the special distribution for the time between arrival and inter-service, eg *M* for the exponential distribution or Poisson which is Markovian, *Er* for Erlang distribution with a number of phases *r*, *G* for general distribution, *D* for deterministic time pattern, and others. *Z* is a notation for queuing disciplines, such as FCFS, LCFS, and so forth. If the notation *K*, *N*, and *Z* is omitted then it is assumed that K = ∞, N = ∞, and Z = FCFS.

One very important parameter in queuing theory is a user-level server (occupation rate) or better known as server utilization. Utilization servers to a single server queuing system and multiserver row can be calculated using the following equation:

$\rho = \lambda \cdot T_s$;   for single server   (1)

$$\rho = \frac{\lambda \cdot T_s}{C};$$ for multiserver (2)

where: ρ = server utilization
λ = the rate of arrival of ships
T_s = the average time of service the ship
C = the number of servers

In queuing theory known as the Little's law [3] which states the relationship between Lw, the number of queues of vessels in the system, Tw, the average time stopped in the system (sojourn time), and λ, the average number of ships coming into the system queue per unit time. Little's Law can be expressed by the relationship:

$$L_w = \lambda \cdot T_w \tag{3}$$

With assuming that the capacity available on the system can meet the needs of ships coming. Little One application of the law on the queue model is to determine the relationship between the queue length *Lq* and the average waiting time in the queue *Tq* which can be expressed as follows:

$$L_q = \lambda \cdot T_q \tag{4}$$

However, if Little's laws applied to the queuing system will be obtained server utilization value as in equation (1).

B. Queue Model in the Port

Broadly speaking, a port provides two types of services, namely transportation of passengers and goods. For the handling of passenger transport is usually the manager is not too much trouble getting because it only takes two service stations, namely dock and passenger terminal to serve passengers, so as a general model for the queue passenger terminal of this type can be illustrated in Figure 1.

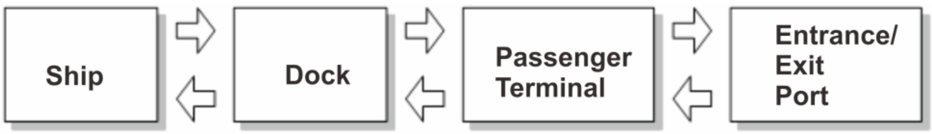

Figure 1. The pattern of passenger service at the port

In passenger services, the queue process can occur in the dock and passenger terminal. The queue at the pier may occur due to dock capacity is limited so that only a few the ship that can be docked and activities up and down passengers, so passengers had to wait a while to be able to disembark or board the ship, while the queue at the port terminal can occur because of administrative problems passenger.

The cases of transportation of goods at the port are usually more complex than passenger transport. There are several processes that must be done so that the goods can descend or climb aboard, including the process of loading and unloading and storage of goods. There are some basic facilities that play a role in handling the transport of goods, namely dock, yard and warehouse. In addition, there are also facilities such as equipment to make the process of loading and transportation of goods.

The process of loading and unloading of goods is usually done by using our port equipment such as cranes, but in particular pier they are using the services of the workers. For the handling of goods already on the ground, there are some general patterns can be seen in Figure 2.

Based on the research that has been done in several ports indicate that the service activities of vessels, from the pattern of arrival and the service has a similar pattern. This research was conducted to develop an approach in the optimization of port facilities particularly in relation to ships queuing system. Queuing system model approach that is widely used today is a model queue M/M/C where time arrivals follow a Poisson distribution pattern, while the arrival time follows exponential distribution. On some models that have been widely discussed, it is usually only used to resolve cases in which each vessel queues have the same priority to obtain service. Such an approach is made only to simplify the calculation considering that each parameter in the queuing system that is included in the calculation of the calculation process will be more complex.

Optimization level of a port facility cannot be based on conditions on the current port only. Currently, the port facilities are adequate, but the condition of the port for the next few years, need to be considered. Some things should be done to determine the condition of the port in the next few years is to make a prediction or forecast about the number of ship visits and the current loading and unloading of goods.

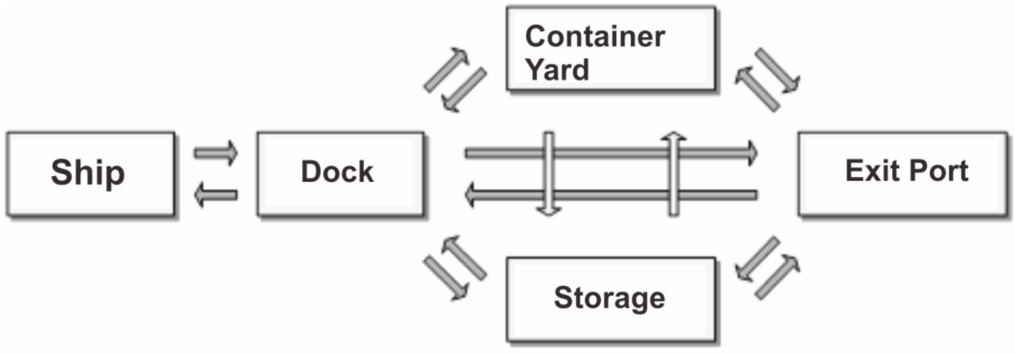

Figure 2. The pattern of goods services at the port.

C. *Fuzzy* Logic

Fuzzy logic is a method to map an input space (domain) into an output space (codomain). Fuzzy set has two attributes, i.e. linguistic and numerical [4]. Linguistic attribute is naming a group that represents a particular state or condition, while the numeric is a number that indicates the size of a variable.

Application of Fuzzy Inference System (FIS) associated with this research is about the control system of fuzzy queue, because one of the conditions that optimizations performed can be achieved is by studying the characteristics of the system will be optimized with the best. Control queuing system will be discussed in this dissertation is more associated with how to model a proper queuing system and policies to regulate the queue system. Both of these cannot be separated when going to the optimization.

In general, control model queue system using fuzzy logic can be seen in Figure 3. In this figure, it appears that the control role in regulating all decisions related to the arrival of the ship in a queue system.

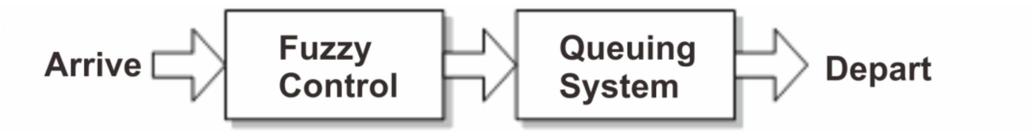

Figure 3. The schematic configuration of queuing system with fuzzy control.

Some of the main things that is an important component in establishing a system of fuzzy control is the process of fuzzification, inference engine, and de-fuzzy all of which are supported by the basic knowledge of the system to be controlled. Scheme of the configuration of fuzzy control system components can be seen in Figure 4.

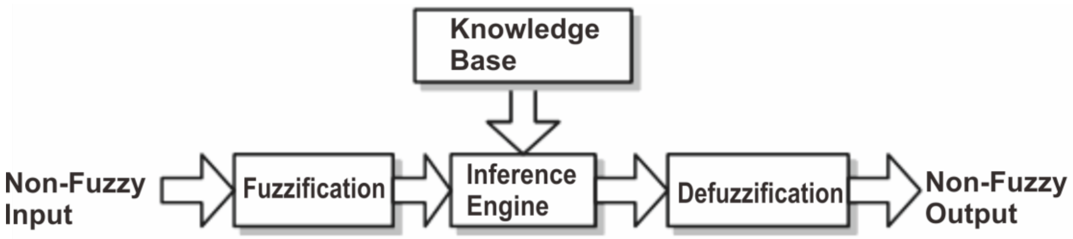

Figure 4. The scheme of fuzzy control system configuration.

Fuzzification process needed to interpret the data that is non-fuzzy input into data in the form of fuzzy membership function with the value of certain membership. The inference engine is the core of the control system as described in the previous section. To build an inference engine that is actually able to provide a solution to the system, the required basic knowledge of the system itself. The output of the inference engine still fuzzy form of data so as to be able to provide the necessary systems problem solving process of interpretation called de-fuzzy process. The output of the fuzzy control system will be used to determine the decisions about what should be done.

III. Methods

In this research, developments of queuing model are using a mathematical approach in the optimization of port facilities, and approaches using fuzzy optimization model. Dock facility optimization model using fuzzy logic is an optimization model to be developed in this study. This model is expected to facilitate the port management in the optimization of port facilities. Therefore, it is necessary to develop some other methods in the optimization of port facilities.

Data required to perform the optimization process of the port facility can be broadly divided into two types, i.e. data is physical and data management. Physical data is data related to the pattern of arrival of the vessel, the performance level of facilities and services, as well as the capacity. Data is data obtained through direct observation in the field. Furthermore, these data can be obtained by performing a prediction of historical data.

Data management is data relating to the policies imposed by the port management in providing services to the ship. One is the management of data is about the queuing system is applied to the queue of ships, goods and passengers. Use a queue system there are no special rules apply to all ships there are some cases that need to apply a special rule.

Statistics from the queue is a statistical calculation process of a model queue. Some of the results obtained from this process is the server utility, the average number of vessels and vessel waiting time either in a queue or in total in a system. This data is indispensable in the process of cost analysis. Statistical process queue is the most important process in the optimization for the results obtained will be a crucial decision, including the appropriate queuing model and the optimal amount of facility capacity.

The cost analysis is a calculation process that determines how much charge is needed to provide adequate facilities and the cost to be borne by the ship to utilize the facilities provided. After each component costs are calculated, and then the two components must be compared with each other in order to obtain the total cost to a minimum. If the minimum has been obtained results it can be determined where appropriate queuing model and the amount of capacity that must be provided by the port management.

Discussion on mathematical model in this study is intended as a comparison to determine whether the fuzzy optimization model developed in this study has been able to provide the expected results.

At the schema optimization process as shows in Figure 5 that the port facilities in this study there are some data ports, such as the number of ship visits, current loading and unloading of goods and services at the port operational performance which includes the performance of ships, loading and unloading performance, and the performance of the equipment. These data can be processed to predict the rate of use of port facilities, namely docks, yard and warehouse, each of which can be expressed by indicators BOR (Berthing Occupancy Ratio), YOR (Yard Occupation Ratio), and SOR (Sheed Occupancy Ratio).

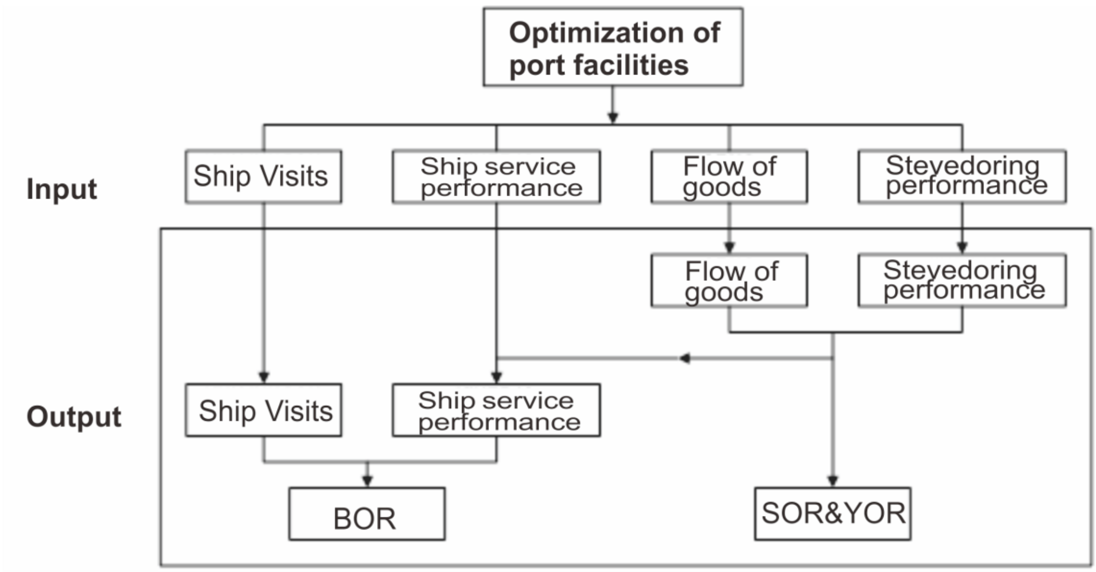

Figure 5. Forecasting the data in the optimization of port

The output optimization process is the level of use of the port facilities which will be used as a parameter for determining the amount of optimization for a port facility. Simulations were performed in this study, includes the calculation of the optimal number of facilities on the quayside mooring performed with mathematical models and fuzzy approach, as well as the calculation of waiting time and queue on a queue system as well as the path of the queue for several different models of queuing systems. Simulations are used to queuing system that has been commonly used Java simulation programs that are already available, while the fuzzy simulation and system priority queue used Matlab 7.1 program.

IV. Results and Discussion

A. Analysis of Model of System Queue

In general, the model of a queuing system that is suitable for a port is determined by the activity of the services provided by the port management. The more activity you want to be given by the Port Authority increasingly complex queuing system model is used. The complexity that occurs can be caused by several factors, among which the difference in the performance level of service provided by each of the service stations, the number of vessels to be served in a server, and others.

Although the existing queuing system at the port as a whole looks complex, but if viewed more closely, it turns out to each pier has a queuing system models are almost the same. The difference lies in the application of different types of services for each pier so that each pier will have different functions.

For example, the ports handle routine activities of loading and unloading of general cargo and fuel, at least to deal with these activities the port should be able to provide two types of docks, the docks to handle ships with transport of general goods (general cargo) and dock to handle tankers. When viewed as a whole, the system model queue for the port is a model of queuing system parallel. To determine whether they are single or multi-server queue server live views from a comparison of the average number of ships coming to the average level of ship services provided by each pier. If the average ratio of the arrival of larger ships an average service of the vessel, the model is in a multi-server queue, but if that happens is just the opposite, the model is in a single server queue. Based on this analysis it can be said that the difference in the type of service provided does not affect significantly queuing system model.

B. Optimization of Sea-Port using Mathematical Model

This section will discuss the results of the optimization on multiple ports by using a queuing system model M/M/C. As one example of a case that will be discussed in this section is the optimization of the dock to the port of Tanjung Perak, Surabaya, Indonesia. Table 8 shows that the number of arrival of the vessel at the port of Tanjung Perak in 1995 amounted to 14 370 units. If the operating time of one year is equivalent to 365 days, the average arrival of the ship per day during the year is:

$$\lambda = \frac{14.370}{365} = 39{,}37 \approx 39 \text{ ship/day}$$

At that time, the number of mooring available for the entire pier is 52 units, while the utilization rate of the pier (BOR) is 78.4%. The average price level of service the ship is:

$$\mu = \frac{\lambda}{\rho \cdot \mathrm{C}} = \frac{39}{0{,}784 \cdot 52} = 0{,}97 \text{ ship/day}$$

Average service ships at Tanjung Perak port for several years are shown in Table 1

Table 1. Calculation of the average ship service at the port of Tanjung Perak

Years	**Ship Number**	**BOR**	**λ**	**μ**
	(unit)	(%)	(ship/day)	(ship/day)
1995	14.370	78,4	39	0,97
1996	14.993	79,5	41	0,99
1997	15.309	78,0	42	1,03
1998	14.565	69,0	40	1,11
1999	14.285	70,0	39	1,08
2000	14.492	79,5	40	0,96
2001	15.669	78,0	43	1,06
2002	13.954	69,0	38	1,07
2003	15.624	70,0	43	1,18
The average level of ships service				**1,05**

If the dock is applied a queue system with the model M/E2/C, where the pattern of arrivals follow a Poisson distribution and patterns of ministry while following the Erlang's distribution consisting of a two-phase exponential pattern of service. The results obtained can be seen in Table 2 and Figure3. Using the same way, a long dock that is optimal for the 2005, 2010, and 2020 with the model M/M/C can be seen in Table 3.

Tabel 2. Simulation of queue system with model M/E2/45

Parameter	**Value**	**Performance Measure**	**Mean**	**Std. Dev.**
Arrival rate	40.0	Number of customers	38.956	7.055
Mean service time	0.952	Sojourn Time	0.974	0.676
Mean time per phase	0.476	Waiting Time	0.022	0.064
Number of phases in service	2	Conditional Waiting Time	0.112	0.106
Number of Servers	45	Busy Period		
Occupation Rate	0.846	Idle Period		

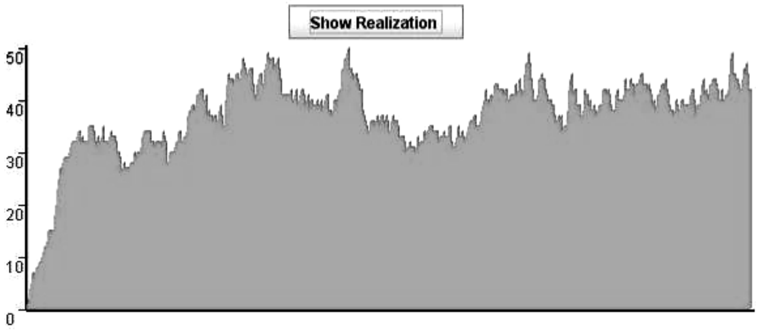

Figure 3. Simulation of queuing system M/E2/45

Table 3. Analysis of Tanjung Perak port with the model M/M/C

Years	Ship Number (Unit)	Average Ship (Unit/day)	Total Mooring (Unit)		
			BOR 70%	Minimal Costs	BOR
2000	14434	40	54	45	84,66
2005	19510	53	73	59	85,55
2010	24591	67	92	74	86,23
2020	34966	96	131	105	87,07

Based on calculations required number of mooring in the port of Tanjung Perak as shown in Table 3, it can be seen that the average additional mooring units required approximately 3 units each year.

C. Optimization of Sea-Port using Fuzzy Model

Calculation of port facilities optimization with fuzzy logic models using the same assumptions the mathematical model, namely the arrival of ships has a Poisson distribution of patterns while the service time has an exponential distribution pattern with unlimited resources. Optimization of these port facilities has been using FIS with Mamdani method. After doing the analysis and testing of the relationship between each of the input data with the expected results, it can be obtained fuzzy logic model that can apply to all the port. Fuzzy logic models formed consisting of a set of models of membership for input and output variables, fuzzy rules and implications functions are used, and the method defuzzy.

After performing tests on the model set membership and fuzzy rules are applied then use the methods and implications min defuzzy centroid method. As one example, the fuzzy model is applied to the Port of Tanjung Perak. The result of the application of fuzzy models for a wide variety of inputs as a whole can be seen in Figure 4. To determine the level of optimization of a jetty at the port of Tanjung Perak with fuzzy model used the same data to a mathematical model. The mathematical model, assumes that the average ship arrivals per year tends to rise, while the level of service boats at the dock are relatively fixed. Fees and service charges waiting ships also tend to increase from year to year.

The average level of service of the ship at the port of Tanjung Perak is 1.05 ship/day. Having calculated with fuzzy model, the obtained amount in the dock mooring units are optimal for the port of Tanjung Perak as shown in Table 4. As a comparison, if the method FIS is the Sugeno method then obtained different results when used in the comparison model the average arrival of the average service and model of cost comparisons wait to charge the same service with the Mamdani method model output different be constant with parameters as shown in Table 5.

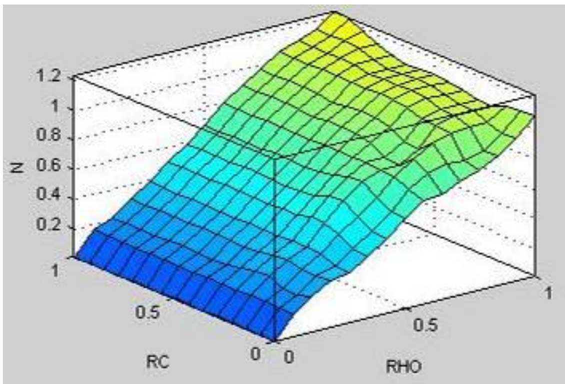

Figure 4. The output of the optimization model FIS Mamdani

Table 4. Optimization mooring in the port of Tanjung Perak using Mamdani FIS models

Years	***RHO***	***RC***	***N***
2000	38,10	2,31	45
2005	50,48	2,81	62
2010	63,81	3,31	78
2020	91,43	4,32	94

Table 5. Optimization mooring in the port of Tanjung Perak using FIS Sugeno models

Years	***RHO***	***RC***	***N***
2000	38,10	2,31	42
2005	50,48	2,81	67
2010	63,81	3,31	82
2020	91,43	4,32	111

V. Conclusion

1. Development of optimization models using approximation queuing system model with servers that use pattern Erlang services provide better results than the exponential pattern of services that are widely used today. The pattern of Erlang services is considered more realistic for the conditions in the port.

Distribution	Single server		Multiserver	
	MODEL	T_w (day)	MODEL	T_w (day)
Exponential	M/M/1	1,0000	M/M/2	0,6690
	M/M/1 PR	0,1704	M/M/2 PR	0,1884
	M/M/1 NP	0,1689	M/M/1 NP	0,2141
Erlang	$M/E_2/1$	0,8750	$M/E_2/2$	0,6290
	$M/E_2/1$ PR	0,1505	$M/E_2/2$ PR	0,1696
	$M/E_2/1$ NP	0,1475	$M/E_2/2$ NP	0,2056

2. Calculation of fuzzy model is relatively faster than the existing mathematical models and results can be obtained directly without iteration process. To determine the optimal dock unit in 2010, using a fuzzy model is obtained directly result is 78 units. While the mathematical model will be needed at least 12 iterations to get the 74 units. Fuzzy model has high flexibility compared with the mathematical model. This can be proved by changing the input variables, the form of the average arrival time of the service, the cost of waiting and service charges, so the fuzzy optimization models provide a solution without having to change the model.
3. Developing of methods of optimization through fuzzy model for complex queuing system using the FIS should be one of the appropriate methods to determine the optimal number of units dock with a total consideration of minimum fees.

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