A Model for Tuna-Fishery Policy Analysis: Combining System Dynamics and Game Theory Approach

E. Widodo, Budianto
Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember, ITS, Surabaya, Indonesia
(erwin@ie.its.ac.id, budianto13@mhs.ie.its.ac.id)

Abstract – **This paper describes a development of tuna fishery policy analysis using a combination of System Dynamics (SD) simulation modelling and Game Theory (GT) approach under a particular project to assure the sustainability of tuna fishery industry. The project was taking place in a coast called as *Sendang Biru* village, Malang Regency, Indonesia. The simulation to achieve fishery sustainability is done by SD approach, while the policy decision-making is done by GT approach. The method used in this project is flexible and expandable. It can be used to provide a comprehensive policy analysis for local government and involved parties in the Malang Regency as a practical benefit as well as broaden connectivity between simulation and modelling tools as a scientific benefit.**

Keywords - **Tuna fishery, system dynamics, game theory**

I. INTRODUCTION

According to Food and Agricultural Organization (FAO), Indonesia is the third largest tuna producer in the world on 2010, after Japan and China [4]. The tuna fishery in Indonesia has developed so much which showed by the significant increase in the fish exploration and exploitation activities in the last decade. The uncontrolled exploitations can degenerate the stock of fish as well as profit in fish industry in the long period of time.

According to Damianus Suryanto, Head Researcher in Indonesia Fisheries Research and Development Center, tuna need to get special attention because it has the highest exploitation rate among other type of fish in Indonesia for the last decade [8]. Most of these tuna is exported to Japan, Thailand, USA, China and Europe. A lot of these tuna are produced at the coast of *Sendang Biru* in Malang Regency, which is the largest grade "A" tuna producer in the entire East Java, Indonesia.

In Malang Regency, the production of tuna is having an increasing trend from 2005 to 2010 but after 2010 the production is tend to decline (shown by figure 1). In the other hand, the number of boat is tend to increase from time to time for the last decade. This is a counter-intuitive effect, where increasing number of boat commonly will cause higher production (before 2010), but in this case (after 2010) the production is declining because of the over-exploitation activities several years before.

System dynamics (hereinafter referred as SD) approach has been widely used to analyze a number of ecology-concern problems such as energy management [6], population health [5], or even fish nursery [2], including about tuna [7]. However, there is still very limitted number of works have been dedicated to analyze and give solution to fishery problems. For example, according to [3] in her research, SD is suitable to map the high tuna fishery complexity and its behavior-pattern along with the flow of time. Another research also made by [4] in the coast of *Sendang Biru* using SD approach, he cited that such approach is suitable to describe the tuna dynamic population.

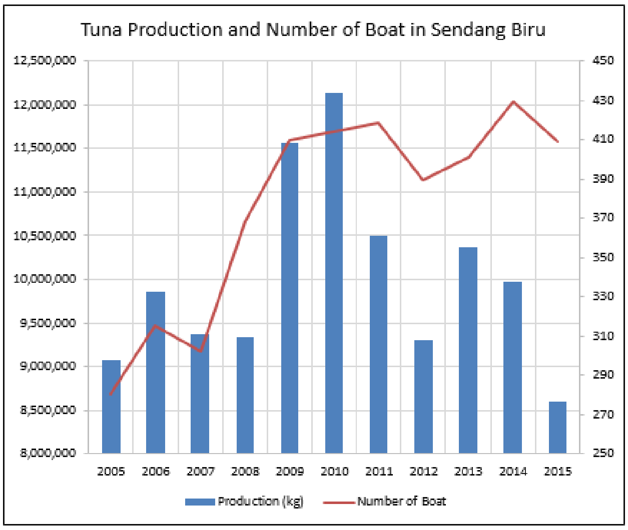

Fig. 1. Tuna production in *Sendang Biru* from 2005 to 2015 [1]

However, all of above mentioned works still have a drawback when exploring system under discussion for tuna fishery comprehensively. Only applying SD approach for doing policy analysis is inadequate since there are more than one parties involve in manipulating options to get the best possible outcome for each party. In this study, the parties are local government, fisherman, and fish trader. In overcoming this challenge, game theory (hereinafter reffered as GT) approach is used. In applying this approach, interaction amongst parties could be accomodated to provide win-win solutions.

II. METHODOLOGY

The tuna fishery system is constructed by first, develop the conceptual model as prescribed in SD approach. This step is then followed by translating the conceptual model into a simulation model. These SD model is used to see the behavior of the tuna fishery system when some input is changed. At last, the best strategy for every party is determined by GT method. The framework of this research is shown by figure 2 below. The decision variables inputted into SD simulation model will be the strategies for players (local government, fisherman, and fish trader) in GT payoff matrix, while the simulation output will be the payoff for each player.

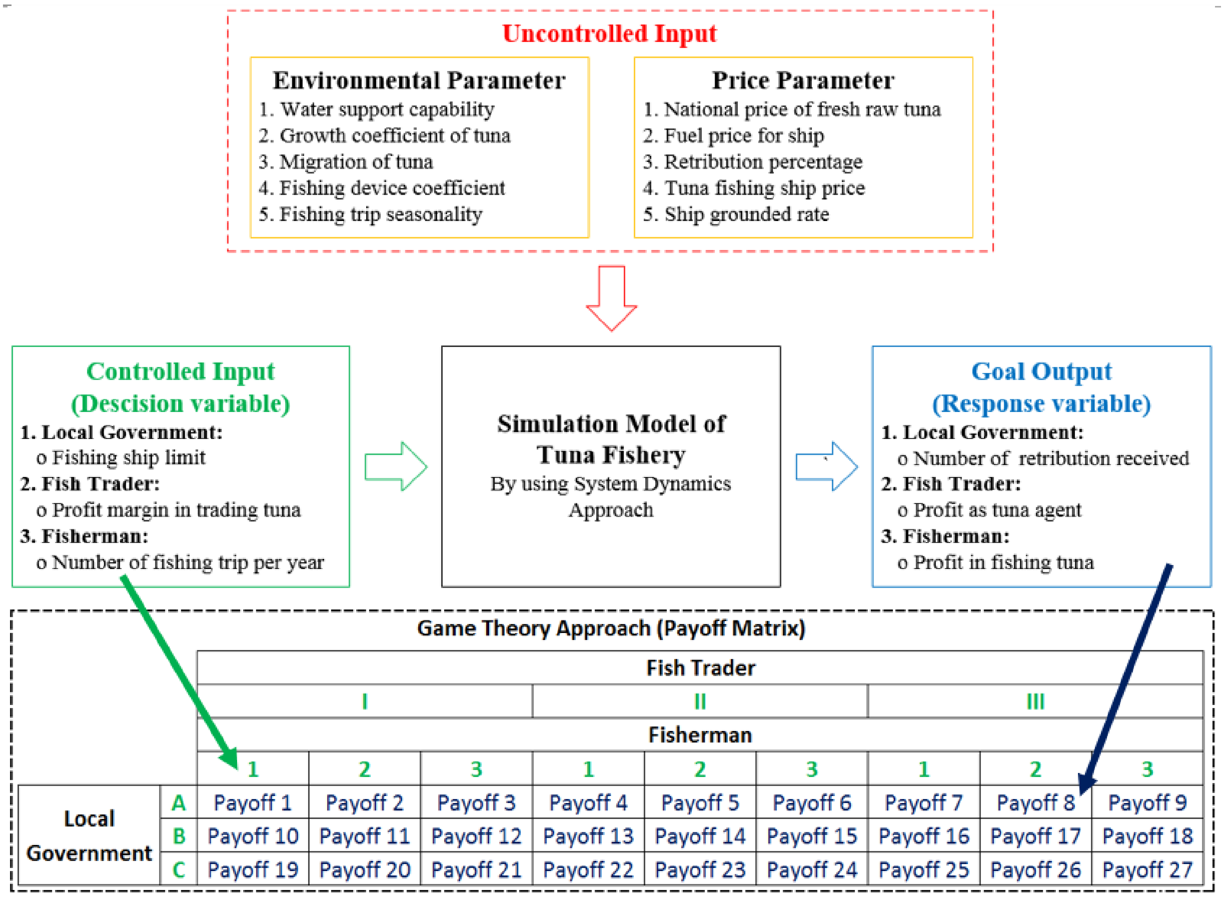

Fig. 2. Research framework combination of system dynamics and game theory approach

III. SYSTEM DYNAMICS

The conceptual and simulation model is made based on the SD approach, using STELLA software.

A. Conceptual Model

The conceptual model is developed using causal-loop diagram to describe the system's feedback structure in the tuna fishery system. The basic concept of SD Modelling of Tuna Fishery using the causal loop diagram is shown by figure 3.

The causal loop diagram is divided into 3 sectors (tuna population sector, fishery sector, and finance sector). Tuna population sector objective is to maintain the stock of tuna, while the fishery sector is to catch more fish with minimal effort. The finance role is to show the profit of each parties and the purchasing of new fishing boat.

This causal-loop used causal link to show the cause and effect among system variable (green arrow show positive relationship, while red arrow show negative relationship).

B. Simulation Model

The simulation model is developed using stock-flow diagram based on the conceptual model (Figure 4). In the tuna population sector, growth rate is a flow that increase the stock of tuna, while number of catches is decreasing the stock. Migration is simulated using stock-conveyor module with the transit time of 4, so tuna that migrate out will come back 4 month later. Number of catches is affected by effort and CPUE (catch per unit effort) from the fishery sector.

In the fishery sector, CPUE is increasing if the number of tuna stock increase. Effort is affected by number of fishing trip and number of boat. The more the trip and boat, the more effort will be. The boat is divided into local boat and foreign boat. The number of boat is constrain by government regulation and income of local fisherman for buying new boat.

In the finance sector, fisherman income is divide into local fisherman income and foreign fisherman income. The government retribution and number of new boat is affected by this local fisherman income. It is important to note that foreign revenue for local government is out of the system in this research and will not be discussed further. The local fisherman income is affected by its revenue and the total cost. The local fishermen revenue is affected by the number of catch and the selling price to fish trader. Fish trader revenue is based on the profit margin between the buying price from fisherman and the national price for selling tuna. The national price is fixed, so to increasing profit margin fish trader need to suppress the tuna buying price from fisherman.

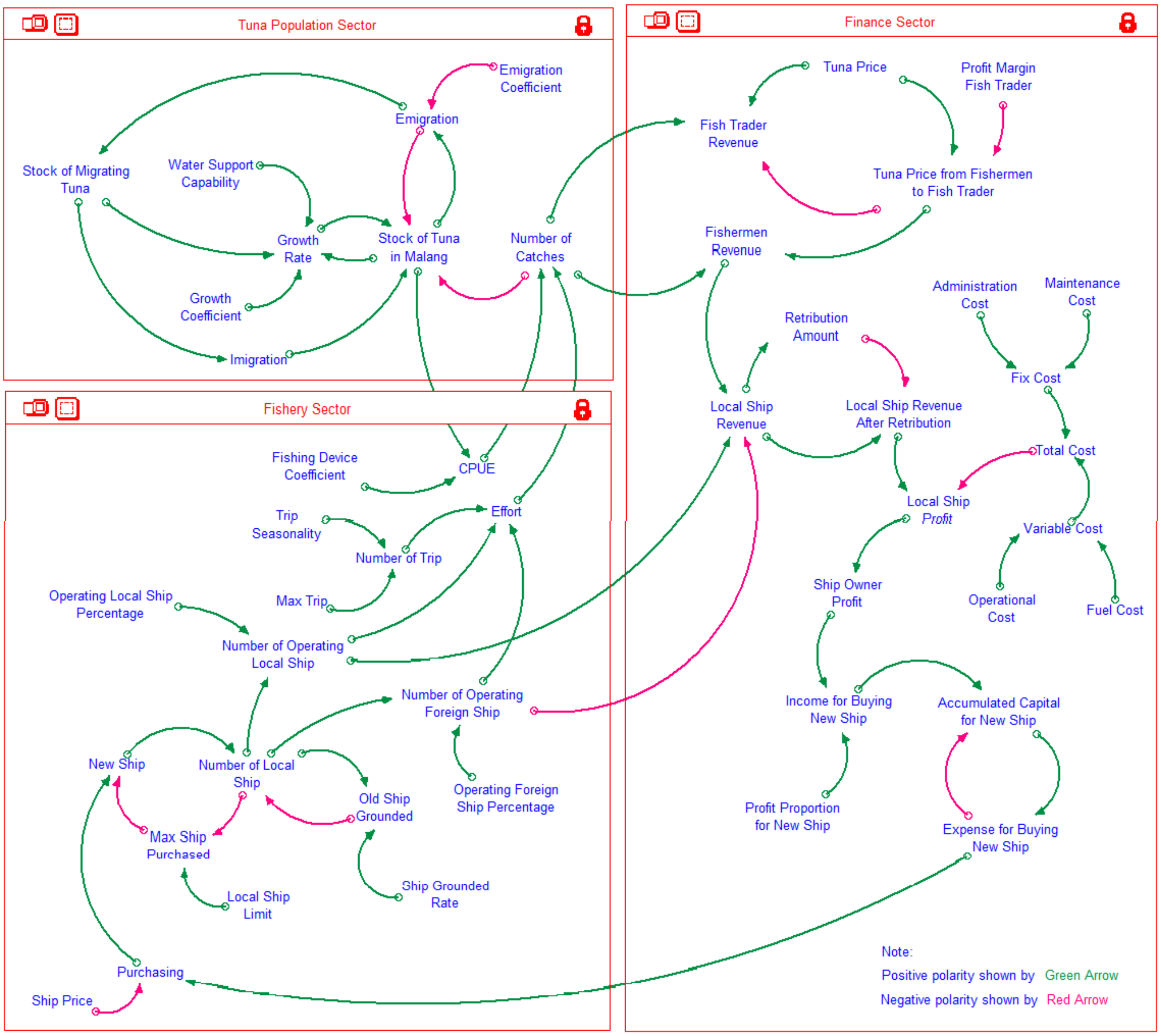

Fig. 3. Causal-loop diagram for tuna fishery system using STELLA software

IV. GAME THEORY

GT is applied to find the win-win solution for each party (called players) with different interest. The local government and fisherman tend to have the same interest, because the revenue of fisherman and retribution to government is directly proportional (3% retribution). On the other hand, fish trader interest is in the opposite direction to both aforementioned players. This third player is understandably to surpress tuna buying price as low as possible. In addition, there is also exist a trade off between to catch tuna as much as possible in a short-term period and to maintain tuna sustainability in a long-term. Hence, to propose a solution to such problem, GT is used in this research.

In a game there are 3 main elements, which are players, strategy, and payoff. For this tuna fishery game, the players are local government, fisherman, and fish trader. The strategy for local government is by limiting the number of local fishing boat, through the boat license. Strategy for each player are shown below.

1. Local Government: Number of licensed tuna fishing boat (less, medium, many at the value of 150, 200, and 250 boats respectively)
2. Fisherman: Number of tuna fishing trip per month (less, medium, many at the value of 2, 3, and 4 trips respectively)
3. Fish trader: Profit margin for trading tuna (low, medium, high at the value of 20, 30 and 40 percent respectively)

The payoff for government is the retribution amount, the payoff for fisherman and fish trader are their own incomes. The payoff matrix is generated based on the player, strategy, and payoff (Figure 5).

Payoff for each player in every choosen strategy is generated based on the SD simulation result. For example, if the strategy for local government is limiting 150 boats, for fisherman is doing 3 fishing trips monthly, and for fish trader is setting 30% margin, their payoff respectively are 42 billion rupiah for local government, 979 billion rupiah for fisherman, and 827 billion rupiah for fish trader.

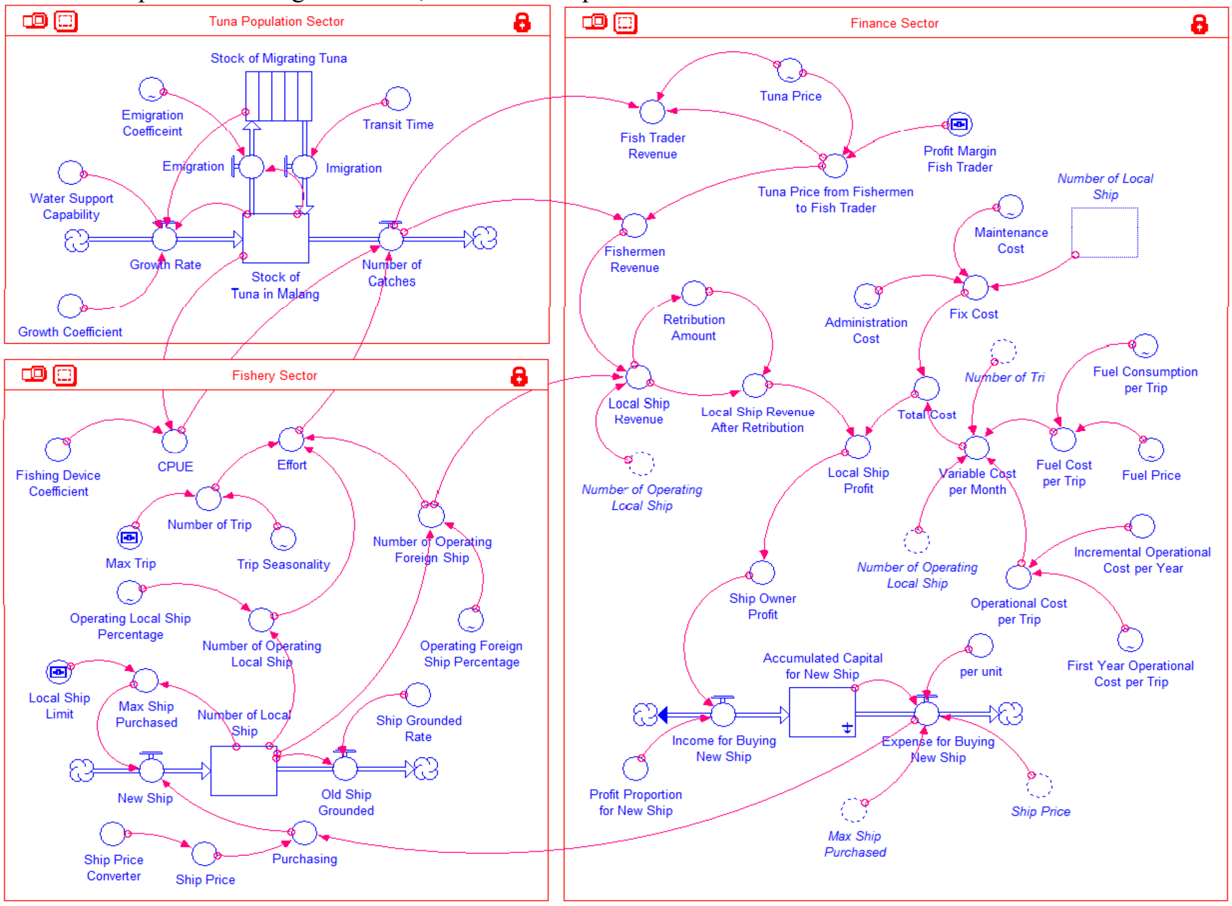

Fig. 4. Stock-flow diagram for tuna fishery system using STELLA software

		Fish Trader								
		20 percent			30 percent			40 percent		
		Fisherman								
		2 trips	3 trips	4 trips	2 trips	3 trips	4 trips	2 trips	3 trips	4 trips
Local Gov.	150	(35, 899, 465)	(45, 1090, 597)	(50, 1130, 660)	(33, 802, 645)	(42, 979, 827)	(46, 1000, 913)	(30, 724, 795)	(39, 878, 1010)	(43, 895, 1120)
	200	(42, 1030, 552)	(51, 1150, 670)	(51, 1000, 670)	(39, 930, 767)	(47, 1020, 928)	(47, 889, 934)	(36, 831, 935)	(43, 916, 1140)	(44, 788, 1160)
	250	(46, 1100, 603)	(53, 1130, 695)	(50, 867, 661)	(41, 975, 816)	(49, 1020, 964)	(46, 780, 918)	(37, 860, 973)	(45, 912, 1190)	(43, 701, 1140)

*** payoff unit is in billion rupiah for 10 years**

Fig. 5. Game theory payoff matrix between local government, fisherman, and fish trader

V. RESULTS

The focus on this research is to find the best sustainable strategy for local government, fish trader and fisherman. The Nash equilibrium (the best chosen strategy) for payoff matrix in figure 5 is:

1. Local Government (many): Set the limit of fishing boat at 250 or more.
2. Fisherman (medium): Go fishing 3 trips every month, do not over-exploit the tuna
3. Fish Trader (high): Set 40% profit margin in trading tuna

The best scenario for local government (250 fishing boat), fisherman (3 trips), and fish trader (40%) are respectively 45, 912, and 1190 billion rupiah. This result is better than that in current situation where profit of local government, fisherman, and fish trader are estimated to be 43, 701, and 1140 billion rupiah respectively (local government do not limit number of boat, fisherman do 4 fishing trip, and fish trader set around 40% profit margin). The SD simulation result of this scenario is shown by figure 6 below. The simulation graph shows that stock of tuna and number of catch are oscillating. This is caused by tuna migrating movement behavior. The number of local boat is not increasing on the early of the simulation because of boat purchasing delay. The number of local boat also increasing if new boat is purchased and decreasing if old boat has breakdown.

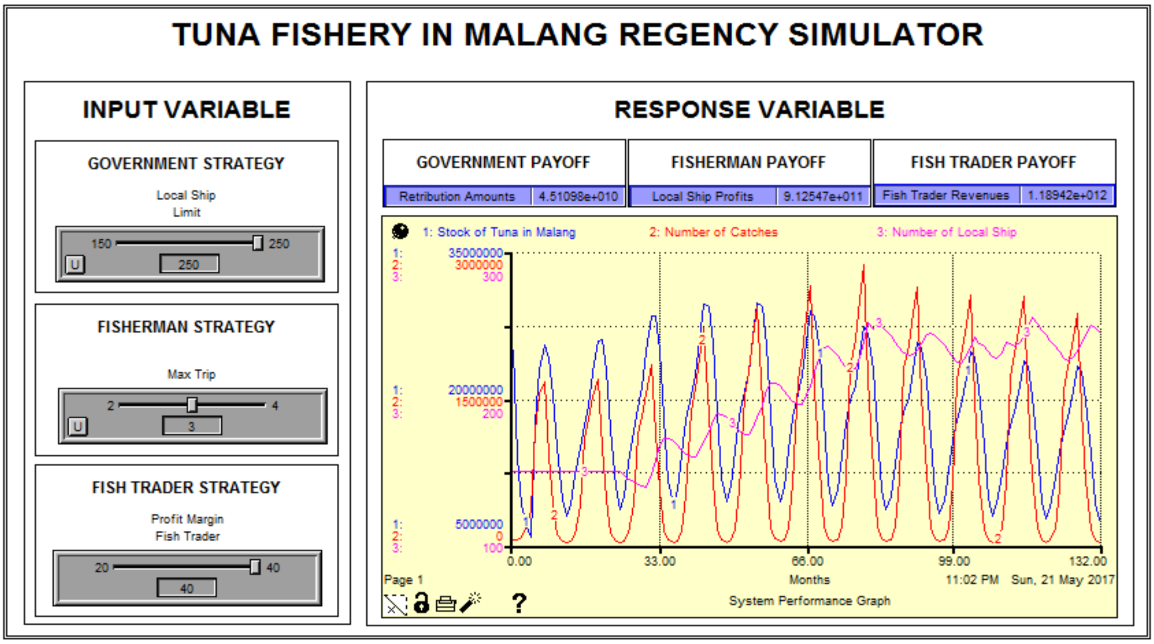

Fig. 3. Causal-loop diagram for tuna fishery system using STELLA software

VI. DISCUSSION

The simulation graph shows that the stock of tuna and number of catch are increasing in the early of simulation, but going down in the end of simulation. This is becaused of the increasing number of local boat in the early to more than half of the simulation. At the nearly end of the simulation, the number of local boat is tend to constant. When the number of local boat is constant, stock of tuna and number of catch are also tend to constant. This constant sustainable level is the most profitable level for all local government, fisherman, and fish trader in the long period of time.

Based on the chosen strategy from payoff matrix in figure 5, the player who has most control in not over-exploiting tuna is the fisherman. They should limit the number of fishing trip to a certain treshold value in order to keep tuna sustainability.

VII. PROVISIONAL RESULTS

This study demonstrate the development of tuna fishery policy analysis using the combination of SD simulation modelling and GT approach. The development a model of tuna fishery policy analysis using combined SD and GT approach provides an effective decision making mechanism to the policy makers. This study describes advantage and benefit of SD modelling which provides clear simulation for tuna fishery dynamic system and a practical multi-parties decision making by implementing Nash equilibrium concept under GT.

As our further development, current tuna fishery model is going to be expanded and adapted into different kind of fishery in a different place with more involved parties to capture data richness so that the policy analysis could be performed more comprehensively. In this research, the foreign fisherman is not included in the system which they also contribute to local government income. Considering foreign fisherman into the system might give different result for the decision makers. Thus, further development is necessary.

REFERENCES

[1] Administration of Sendang Biru Village Government, *Tuna Production from 2005 to 2015,* Malang, 2015.

[2] M. Cordier, T. Uehara, J. Weih, B. Hamaide, “An Input-output Economic Model Integrated within a System Dynamics Ecological Model: Feedback Loop Methodology Applied to Fish Nursery Restoration,” *Ecological Economics*, vol. 140, pp. 46-57, 2017.

[3] E. Fatma, "Development of Sustainable Tuna Processing Industry using System Dynamics Simulation," *Procedia Manufacturing,* vol. 4, pp. 107-114, 2015.

[4] Food and Agricultural Organization of the United Nations, "Recent Development in the Tuna Industry," *FAO Fisheries and Aquacultural Technical Paper,* vol. 543, p. 17, 2010.

[5] A. Hill, O. M. Camacho, “A system dynamics modelling approach to assess the impact of launching a new nicotine product on population health outcomes,” *Regulatory Toxicology and Pharmacology*, Vol. 86, pp. 265-278, 2017.

[6] X. Liu, M. Zeng, “Renewable energy investment risk evaluation model based on system dynamics,” *Renewable & Sustainable Energy Reviews*, Vol. 73, pp. 782-788, 2017.

[7] G. Warsito, "Developing Sustainable Tuna Fishery Policy for Malang Local Government," Sekolah Tinggi Teknologi Angkatan Laut (STTAL), Surabaya, 2017.

[8] S. Yunita, "Tuna Over-Exploitation," *Kompas Daily: Science of Environtment and Health,* p. 14, 26 11 2016.