Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 4 (2015) 107 – 114

Procedia MANUFACTURING

Industrial Engineering and Service Science 2015, IESS 2015

Development of sustainable tuna processing industry using system dynamics simulation

Erika Fatma*

Logistics Management of Electronic Industry, Politeknik APP Jakarta, Jakarta, Indonesia

Abstract

The increase of the world demand for tuna-processed products needs to be balanced with tuna and tuna-fish like sustainability in their environment. Sustainable management system is needed to increase the production of tuna processing industry by still preserving its sustainability. This problem became more complex, due to the dynamic nature of ecosystems and other processes involved. This study developed a system dynamics model which integrates tuna stocks ecosystem, tuna processing industry development, social economic, and policy sub-models. This model was developed based on historical data, then developed into three development scenarios: without fish-catch limitation, limitation by Sustainable Maximum yield (MSY) and limitation by Maximum economic yield (MEY). System dynamic modeling was conducted to analyze sustainable tuna industry development based on various points of view, to accommodate stakeholder interest. The success of tuna processing industry development, were assessed from the increase of production values, the preservation of tuna and tuna-like fish stock in the environment, and also the improvement of social welfare. Simulations were carried out for 25 years to predict the condition of fish stocks in the future, based on current policies applied. Simulation results show that to develop tuna processing industry while maintaining the stock of tuna in its sustainable conditions, only limiting the fish catch was not enough, the process of integrating industry, socioeconomic and policy made by related institutions were also important.

Keywords: System dynamics, sustainable industry

* Corresponding author. Tel.: +62 21 7270215; fax: +62 21 7271847.
E-mail address: rika-fatma@kemenperin.go.id

2351-9789 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer review under responsibility of the organizing committee of the Industrial Engineering and Service Science 2015 (IESS 2015)
doi:10.1016/j.promfg.2015.11.020

1. Introduction

Tuna is one of the most important fishery commodities in Indonesia; the commodity supplies the domestic and global demands. There are many fishes in the category of tuna fish, but only four types of tuna give a considerable contribution for the tuna fisheries in Indonesia in forms of big-eyed tuna (Thunnusobesus), blue-finned tuna (T. mac-coyii), madidihang (T. albacares), and skipjack tuna (Katsuwonuspelamis) [1]. The potency of tuna fisheries in Indo-nesia is expected to be 374,047 tons. Most of this potency is located in the eastern area of Indonesia, particularly in the north water of Sulawesi, Papua, and Arafura Sea [2].

The tuna commodity from Indonesia and its processed products have a high competitiveness in local and global markets. The development of tuna-processing industry in Indonesia is very prospective considering the high stock of fish, availability of markets, and government support in fisheries revitalization. The development of tuna- processing industry can increase the foreign exchange, create the business opportunity, absorb the labor, and improve the prosper-ity of people, especially fisheries community. The demand of the global market for tuna-processed products from fish is considerably high. Unfortunately, the national tuna-processing industry is still very small as it is only contributes 9% of the total consumption in the world. This rate is lower compared with the percentage of canned fish from the neigh-boring countries, such as Thailand and Philippines [1].

The purpose of the policy in the development of Maritime and Fisheries in the Government Work Plan 2012 related to the fishery industrialization is the improvement of fishery production and its competitiveness. The development of the processing industry will be followed by the increasing demand on tuna supply. Therefore, the tuna fishing must be observed in order to prevent the threat of tuna resource depletion. This threat comes from the increasing consumption in the world in which the fish becomes the important source of protein and the target of economic growth from fisher-ies-processing industry sector. This condition is worsened by the characteristics of common property in sea resource, the weak supervision, high fishing rate, and practice of illegal fishing [3]. This excessive exploitation is caused by the management method that does not consider the sustainable fishery development principle, so it damages the ecology of coastal area and sea as the habitat of these fishes and the stock of fish is reduced by excessive fishing [4].

The sustainable development in the field of fishery is urgent to be implemented as the condition of fishery in some waters in Indonesia is in crisis. In the sustainable fishery management, there are three approaches of management, namely MSY, MEY, and MScY [5]. Based on Maximum Sustainable Yield (MSY) approach, the total catch is limited on certain level in order to maintain the stock of fish on its sustainable level; the ecological aspect is the focus in this approach. Maximum Economic Yield (MEY) is conducted by determining the total catch based on the highest profit per trip. Meanwhile, Maximum Social Yield (MScY) is conducted by determining the total catch and optimizing the number of fishing until certain limit that does not lower the biomass of fish stock.

North Sulawesi Province has a significant potency of tuna fisheries and tuna-processing industry, mainly located in Bitung. Bitung has Perikanan Samudera Port, which located between two fishery management zones, Maluku Sea (WPP-715) and Sulawesi Sea (WPP-716). The main commodity of fishery in Perikanan Samudera Port is big-eyed tuna (T. obesus), Madidihang (T. albacares), and skipjack tuna (Katsuwonuspelamis). The main commodity to export is big-eyed tuna and Madihadang. Meanwhile, most of skipjack tuna is used as supply for the local market. Based on the data of [2], the statuses of tuna exploitation level in those two Fishery Management Areas are over-exploited for big-eyed tuna fish, fully-exploited for Madihadang fish, and moderate for skipjack tuna [5].

The dynamics and complexity in the development of sustainable tuna fish-processing industry are the dynamic processes. Meanwhile, the current fishery management system is static and less adaptive to use. The dynamic system and simulation approaches are very suitable to analyze mechanism, pattern, and trend of tuna-processing industries, as a set of policy taken based on the desired condition in the future. The system dynamics are used to assess a fundamental structure of complex situations by identifying the pattern of cause from the on-going behavior change. This method is related to the mapping of complex system dynamics trend in which the behavior-pattern awakened by the system is along with the flow of time [6].

This research was conducted to answer on how different approach on fisheries policy can affect industry development and environment. The aim of this research was to develop the simulation model of system dynamics in the sustainable tuna fish-processing industry and its fishery management that considers the fish preservation and sustainability. The resulted model is expected to be used to analyze the factors affecting tuna-processing industry by considering the sustainable potency based on the optimal scenario development. Besides, the result of this research can be used as information and recommendation in compiling the planning and policy making in the development of fish management industry. This research is limited on the effect of fishing, tuna-processing industry in North Sulawesi and society, population and development of human resource in a dynamic system process.

2. Methodology

The research was conducted with system dynamics method, research data were gathered from statistical data of fishery from Ministry of Maritime Affairs and Fisheries, industrial data, Central Bureau of Statistics, local government, and information based on literature study and interview with stakeholder.

The initial stage in this research was problem identification; in this stage, analysis on factors affecting the development of tuna-processing industry based on literature study and field observation was conducted and the result of analysis was entered into causal relation among the identified factors. The next stage was to builds mathematical model based on the statistical data and interview with the related parties. In this research, dynamic system was composed of environment subsystem, industry/economy, and society. Furthermore, verification, validation on the resulted model, and scenario development for forecasting in the future and result analysis were conducted.

The software to accurately assess behavior of the model was required for the mathematical modelling and simulation on the created scenario. This research used the Stella Software version 9.1.3 due to its ability to build and accommodate the dynamic model simulation with interface that was easy to understand. Simulation model development in this research is aimed to give estimation on the condition in the future until year of 2030 based on three scenarios from fisheries management approach.

3. Model development

3.1. Causal loop of tuna-processing industry diagram

In the sustainable development of tuna-processing industry, the system cannot be assessed only from the optimal total catch based on the carrying capacity of environment and environmental sustainability, but it must be supported by the sustainability of other subsystems, namely social, economic, and institutional conditions [7]. The initial stage in this model development was to build causal loop among the factors having relation, relevance among tuna supply, fish production, production rate, and labor absorption level (Fig. 1).

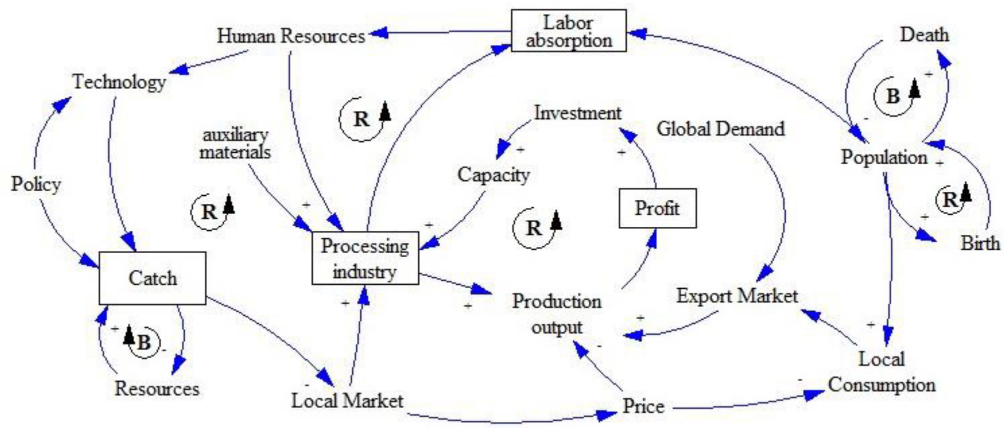


Fig. 1. Causal loop diagram of tuna-processing industry development.

3.2. Environmental sub-model

The modelling developed to predict tuna stock is based on the dynamic model of Schaefer biomass. The available biomass is equal to the change rate of tuna population for biomass inflow reduced by biomass outflow [8]. Based on the perspective of system dynamic, fish biomass model, it can be formulated as follows:

$$\frac{dB}{dT} = rB - rB\frac{B}{k} - qEB \tag{1}$$

The increasing population of fish biomass (B) is flow from the growth of fish based on fish growth rate (r). Meanwhile, the decrease of fish biomass is based on death rate indicated with growth rate multiplied by ratio of fish biomass and possible maximum population of fish (k). The available fish stock is calculated based on population reduced by the total catch, in which the caught biomass is equal to coefficient of catch capacity (q), effort (E), and tuna biomass. Then, this model is translated into the system dynamics model to suppress the relation between variable and how system change from time to time. To create the sustainable tuna management, the balance must be created between growth rate of tuna stock biomass and the production and raw material demand.

3.3. Industry sub-model

Industry sub-model has the role to distribute the facilities in the fishing, in forms of ship, fishing equipment, and employment. Industry development sub-model is affected by the availability of fishery resource stock supplied exclusively by tuna sent to fishing port. Processing industry is formed in certain model by considering the operational indicator used in the production process, the use of capacity installed on tuna-processing industry. The industry must meet requirements and standardization of product referring to the international standard for food safety GMP, and other international standard in order to suppress number of product that does not meet global requirement.

3.4. Society sub-model

In the society sub-model, the population growth becomes the affecting factor. The population will affect the consumption rate. Society sub-model describes economic effect of fishery-processing industry for the prosperity of people and its effect on the income of the country. Good quality tuna-processing activity will encourage marketing of product that will bring positive effect on the income and prosperity of society. The income from tuna-processing industry will increase the value of investment in order to increase the production capacity of fish processing. Another effect is the increasing interest to invest in the sector of human resource development. It is assumed that human resource development also positively affects the awareness on the importance of sustainable processing industry.

3.5. Government policy

The fishery policy is related to the government regulation and the related institution in supporting the development of fishery sector and tuna-processing industry on the economic development and environmental sustainability. The economic policy is the use of economic factor to control fishing and fish management, including price of fish, development of work opportunity, and improvement of quality and fishermen as human resource. The biological controlling is conducted through the limitation of fishing equipment, limitation of effort to maintain the sustainability of resource, and the control of fishing area.

4. Scenario development

4.1 Model verification and validation

Verification is the stage to ensure whether or not the model is suitable with the real situation and condition.

Verification process was conducted by checking the variable unit in the model by conducting check unit on Stella software, and it is found that the model and unit of all variables are verified and acceptable. Validation is model-testing stage, whether or not it is able to describe the real system correctly. This test is statistically conducted by comparing the result of simulation and the actual values acquired from the real data. Verification process and model validation also involve the knowledge about the development of sustainable fish-processing industry to ensure that all relations among variables in this process are reasonable and acceptable.

4.2. Scenario design

Planning and running the scenario system dynamics is conducted to assess the effect of policy change determined in the beginning of simulation. This stage is conducted by changing conditions and/or development on the model, thus the output that is different from the existing model is created. The result of model development simulation is compared with the resulted output and existing output, whether or not it makes a quite significant change. After that, the analysis on value from variable affecting the processing industry development is conducted in order to give consideration for government and other related parties on the policy affecting this industry development.

Scenario design of management is developed based on the development theory of Gordon-Schaefer [9] used in this research; it consists of 3 scenarios as follows:

1) Without limiting the permitted fishing, in this scenario, there is no regulation limiting the total catch in order to meet the demand of market and industry.
2) Determining the limitation of catch through Maximum Sustainable Yield (MSY) approach. On the scenario with MSY approach, the maximum catch is allowed to be in balance, that can be formulated into as follows:

$$\frac{dB}{dt} = h_t = 0 \tag{2}$$

So, the allowed catch per unit effort (CPUE) is as follows:

$$\frac{h_{MSY}}{E} = qK - \left(\frac{q^2K}{r}\right)E \tag{3}$$

3) Determining the catch limitation through the approach of Maximum Economic Yield (MEY). In the approach of MSY, the balance is only counted based on the biological factor. In fact, in the development of tuna-processing industry, economic factor should be considered in which c is the budget required per unit effort, p is the price per weight of tuna. Based on the theory of Gordon-Schaefer, considering the profit factor in the calculation, the allowed catch per unit effort (CPUE) is as follows:

$$h_{MSE} = \frac{r}{2q}\left(1 - \frac{c}{pqK}\right) \tag{4}$$

5. Result and discussion

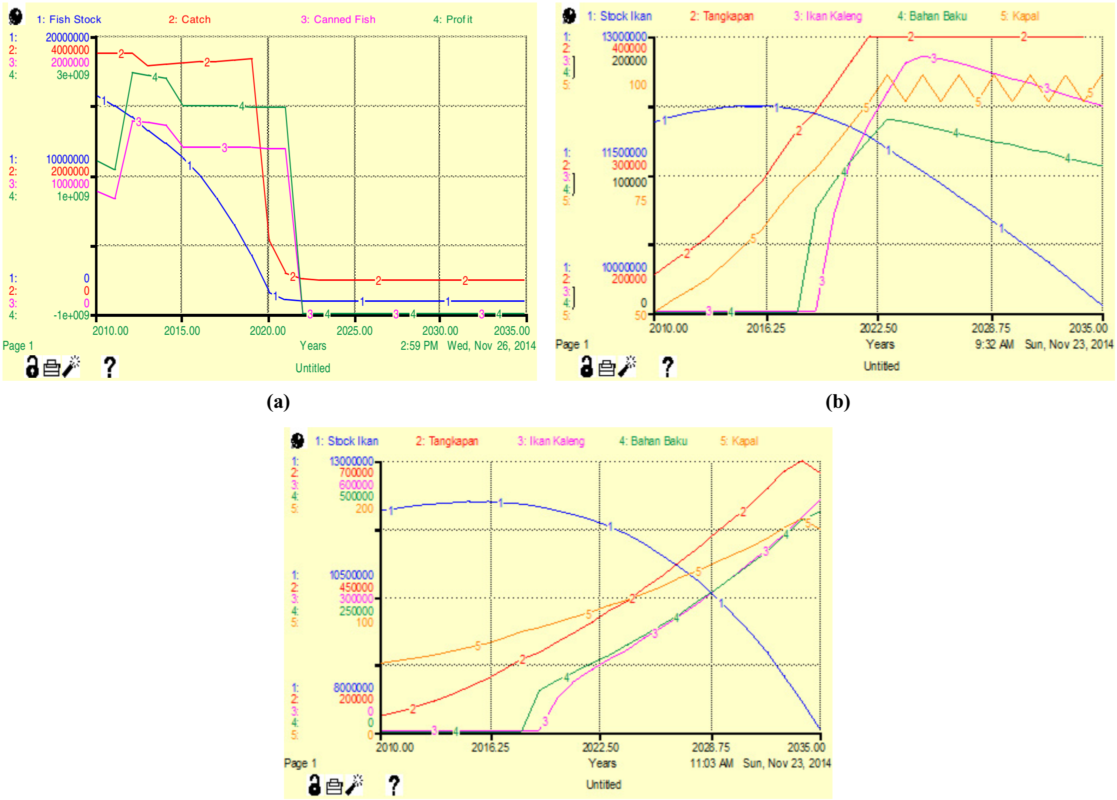
5.1. Existing condition

Samudera Bitung Fishing Port is located on strategic location between two Fishery Management Areas 715 and 716. The statuses of fishery resource in this zone are moderate for skipjack tuna and fully exploited for tuna [2]. PPS Bitung has potency of fishery with the production of 125.9 ton per year and with the production rate of 196.9 ton/year on exclusive economic zone. The used value is from the statistical data processing in the related institution and the research result from [10], researching the sustainable fishery management in PPS Bitung. Tuna production increases averagely by 6.21% per year, with the standard catch per unit effort (CPUE) of 625 ton per year. The intrinsic growth rate of fishery resource in the fishing ground (r) sent to PPS Bitung is 1.51% with the environmental carrying capacity value of 31,284 ton/year and the capture coefficient value (q) of 4.7 x 10-5. Economic parameter is viewed from the operational cost of catch, average price of tuna/kg, and the profit value of tuna-processing industry. Meanwhile, the social parameter can be viewed from the amount of people, population growth in North Sulawesi of 1.14% and the labor absorption.

5.2. Fishery management simulation

The main indicator used in the development simulation for sustainable tuna-processing industry is indicator of every sub-model, tuna biomass stock, total production, and the processed tuna production. Besides, the profit from the fishery and processing industry is used as an economic indicator. Simulation on three scenarios is presented in Figure 2.

Based on the simulation result of the system presented in Figure 2, in the first scenario, without limitation, the availability of tuna will be reduced in a short time. As the result, tuna-processing industries will be stopped by the lack of raw material. In the second scenario, limitation with MSY, the relation between the effort and the total catch is based on the tuna growth rate in the capture area (r), tuna environmental carrying capacity in water (K) and the catch coefficient (q) is based on equation 2., effort of maximum sustainable yield (EMSY) per year of 23,921 trip on the standard purse seine with maximum sustainable yield (MSY) of tuna of 54,360 tons per year. Result for MEY analysis shows that optimum production of 48,370 ton/year and MEY effort of 16,004 trips per year are required. This yield is achieved with the tuna price of IDR 6,000/kg, fish price by catch of IDR 7,000 and cost per sailing of IDR 3,750,000/trip. Investment cost is distributed equally based on the ship's life time and ship machine into annual fix cost of IDR 166,530,000. The profit is the revenue from the sale of captured fish reduced by the trip cost and annual fix cost.



(a) (b) (c)

Fig. 2. Simulation output of every scenario (a) Without limitation; (b) Limitation with MSY; (c) Limitation with MEY

Optimum scenario for environment is based on the indicators of sustainable fisheries of biological, economic, and social dimensions. The scenario chosen in this research is in the intermediate scenario, the best compromise among the government policies in fisheries resource management. Optimum scenario is based on economic indicator, particularly the profit based on the investment to increase industries capacity. MEY scenario shows that investment in improving fish-processing industry capacity gave higher profit. Investment analysis is viewed from Return on Investment (ROI) and Internal Rate of Return (IRR). It can stimulate the interest of fishermen and businessmen in local industry to develop tuna-processing industry in North Sulawesi. Social-based optimum scenario is based on the economic and social indicators. The scenario chosen in this research is in MEY scenario; the application of this scenario will give wider opportunity to people in coastal area and prevent the conflict of interest.

5.3. Policy of sustainable fishery-processing industry

Policy in limiting fishing activities, by limiting size or species catches can be viewed from several perspectives. In terms of fishing equipment, it needs development to be more selective, so by-product is not the effect of the accidentally catch of juvenile fish anymore that can reduce the fish population. The use of environmentally friendly fishing equipment with high selectivity can minimize by-product number. Besides, to maintain the preservation of tuna resource, some approaches can be implemented by reducing effort through Total Allowable Catch (TAC), reducing catch unit, through the open and closed system of fishing area.

Besides the availability of tuna preservation, the development of fish-processing industry in Indonesia still has other obstacles, namely the limitation of ship with hygiene standard affecting the quality of yield, the awareness on quality and product quality that is still low, and the business priority of tuna that is limited to fresh and frozen tuna; all of the obstacles lower the development of the canned tuna industry. The support of government is required to ensure the availability of raw material, the support on the proponent raw materials such as the import facilitation on the can and the support in the upstream, especially to catch tuna. The reduction of fish shows that the average "decrease of production value" is 12.7%, caused by the decreasing quality of fish during fishing, landing, processing, and storing phases. The production increase of fishing can be implemented by suppressing the production decrease of fishing and improving fish-preservation technology to slow the fish damage process before entering the production line.

The investment is required to increase the production capacity for tuna processing, so the yield of tuna has high additional value. The consideration in the investment in fish-processing industry is also related to the ecological factors/environment of raw material (tuna) used in the production process. The investment is beneficial in terms of economy and finance with its return time and profit. Facility is the improvement of facility in the port and tuna landing site supporting cold supply chain through the building of ice manufacturer, adequate facility and supporting transportation, meanwhile Human Resource is the sustainable training on business management technology and international standard tuna processing.

6. Conclusion and suggestion

The simulation modelling of dynamics system is built on the basis of sub-models that relate to and depend on each other. The built dynamic system consists of sub-environment, industry, and society. The complexity in the development of tuna-processing industry and the effect of policy in tuna management make this dynamic system model useful in giving the recommendation to make decisions on the development of effective, efficient, and sustainable fish resource management. The over-fished water territory and the decrease of fish supply, the policy to limit the fishing with MSY and MEY approaches can maintain the tuna stock in the sustainable condition. The balance between the effort to use the tuna resource and the effort to improve the production of processed tuna industry can be achieved by limiting the total catch, improving the fishing equipment technology, the repair of cold supply chain, and improving the quality of processed product based on the international standard. This balance must be implemented to prevent the excessive exploitation that results in depletion of resource and threatens the industry sustainability. The sustainability of tuna processing industry is also determined by the adequate profit to attract investment and provide employment opportunity for people.

References

[1] Martosubroto P., "Kajian Usulan Pembentukan Lembaga Pengelola Perikanan Tuna yang Berkelanjutan dan Bertanggung Jawab," WWF-Indonesia, Jakarta, 2012.
[2] Kelautan K. P., Keputusan Menteri Kelautan dan Perikanan RI. Nomor KEP.45/MEN/2011 tentang Estimasi Potensi Sumber Daya Ikan di Wilayah Pengelolaan Perikanan Negara Republik Indonesia, Jakarta: KKP RI, 2011.
[3] Rachman B., Analisis Pengaruh Kebijakan Perikanan Tangkap Terhadap Rantai Pasok Ikan Pada Kawasan Klaster Industri Perikanan Muncar (Studi Kasus: Industri Pengalengan Ikan Sarden Muncar, Banyuwangi) . Skripsi., Semarang: Universitas Diponegoro, 2011
[4] Nikijuluw V., Rezim Pengelolaan Sumberdaya Perikanan, Bogor: PT. Pustaka Cidesindo. Bogor, 2002.
[5] Widodo., "Jenis dan Distribusi Ukuran Ikan Hasil Tangkap Sampingan (Bycatch) Pada Perikanan Tuna di Samudera Pasifik. Laporan Akhir Kegiatan Penelitian.," Balai Riset Kelautan dan Perikanan, KKP., Jakarta, 2010.
[6] Forrester J. W., "System Dynamics, Systems Thinking and Soft OR," System Dynamics Review, Vols. 10-2, no. 3, pp. 245-256, 1994.
[7] Charles A. T., Sustainable fishery systems, New York: John Wiley & Sons, 2008..
[8] Dudley R. G., "A Basis For Understanding Fishery Management Dynamics," Journal of System Dynamics Review, vol. 24, no. 1, pp. 1-29, 2008.
[9] Fauzi A., Pemodelan Sumber Daya Perikanan dan Kelautan, Jakarta: Gramedia Pustaka Utama, 2011.
[10] Widodo, J. S., "Pengelolaan Sumberdaya Perikanan Laut," Gadjah Mada University Press, Yogyakarta, 2006