Interaction between Marine Sectors using System Dynamics for Patimban Deep Sea Port as a Green Port: A Proposed Model

Tatang Suheri1,a, Mohammad Benny Alexandri2,b, Sam'un Jaja Raharja2,e, Margo Purnomo2,d, Sparisoma Viridi3,e

1Department of Urban and Regional Planning, Faculty of Engineering and Computer Science, Universitas Komputer Indonesia, Bandung 40132, Indonesia
2Department of Business Administration, Faculty of Social and Political Science, Universitas Padjajaran, Sumedang 45363, Indonesia
3Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung 40132, Indonesia

atatang.suheri@email.unikom.ac.id, bmohammad.benny@unpad.ac.id, crahairja2017@unpad.ac.id, dpurnomo@unpad.ac.id, edudung@fi.itb.ac.id

Abstract. Based on Marine Policy Statement (MPS) some sectors are chosen as the key elements, whose interactions are modeled using system dynamics (SD). They are port, commercial shipping, marine protected area, and commercial fishing. Besides those, according to MPS and beyond the coastal area conversion of agricultural land into the industrial area due to commercial shipping, maintenance of state roads due to port (shifting from Tanjung Priok port), redistribution of population, and environmental aspects will also be taken into account in the model. Some of the elements will construct reinforcing (R+) loops, while the others construct balancing (B-) loops in finding an equilibrium or solution. Several scenarios are proposed, where each has a different set of parameters, that can reflect a certain policy. Due to the lack of certain data and information related to the deep seaport, most of the data used in this work are based on assumptions but with a logical causal relationship between elements. It is observed that some features in the results are as expected, but some are new and depend on the chosen scenario. Further benchmarks with real situations are required for validation of the model.

1. Introduction
System Dynamics (SD) has been used a lot in coastal area, e.g., for improving value of cosystem services in Shinduri coastal area in South (Korea You et al., 2018), for managing sustainable tourism using a decision support system in Cijin, Kaohsiung, Taiwan (Tan et al., 2018), for predicting the sustainability of tuna ranching industry in Mexico (Robadue & del Moral Simanek, 2007), for simulating forward scenario of sustainability landscape in Cimandiri Estuary, West Java, Indonesia (Supriatna et al., 2016), for assessing of the impacts of storm damage on coastal communities in Chabahar Bay, Iran (Moradi et al., 2020), for observing appropriate technology application in Aboriginal New South Wales coastal community, Australia (Jokhu & Kutay, 2020), for analysing the eco-aquaculture system of integrated aquaculture park in Malaysia (Isa et al., 2020), for
conceptualizing social-ecological system dynamics in the Bangladesh delta (Hossain et al., 2020), for simulating of a port–city green cooperative development, Shanghai Port, China (Li et al., 2019), for assessing surface water resource of paddy rice production under climate change in Mekong Delta, Vietnam (Tuu et al., 2020), and for increasing ocean literacy (Brennan et al., 2019).

In the future, a seaport should shift to use renewable and green power systems due to the increment of fuel prices and also push from international environmental regulations (Sadek & Elgohary, 2020). Patimban area has abundant sunshine hour, which can be converted into solar energy that 150 times higher compared to the approximated energy demand of the deep-sea port (Julian et al., 2020).

2. Model

2.1. Causal loop diagram

In constructing the model using system dynamics (SD) in this work we will use a causal loop diagram (Bala et al., 2017), which will map only some of the marine sectors (MMO, 2014) and some additional aspects from a local scope. We are very inspired by the interaction between the port and the city in the case of Shanghai Port (Li et al., 2019), which is modified and advanced as shown in Figure 1.

![Causal Loop Diagram](image-url)

**Figure 1.** Causal loop diagram for Patimban Port, which relates port, city, green technology, population, and also interstate aspect, where for city and port gross domestic product (GDP) feature is chosen.
Five main nodes will be the focus of this work, where they are indicated by a box with a dashed line and rounded corner: Green Technology (green), Port-Driven GDP (yellow), Urban GDP (blue), Population (red), and Interstate Industry – Infrastructure (purple). The first will be an enabler for the green port, the second and the third show the importance of port development in increasing economy, the fourth is a unique feature of in-migration in Indonesia when a central economy is developed, and the last is the shift that will happen to the use of interstate infrastructure, e.g. highway and port for shipping interstate industry products.

From Marine Management Organisation (MMO) there are several sectors, which are Aquaculture, Carbon Capture and Storage (CCS), Commercial Fishing, Commercial Shipping, Defence, Marine Aggregates, Marine Protected Areas (MPAs), Nuclear Energy, Offshore Renewables, Oil and Gas, Ports, Dredging and Disposal, Recreation, Surface Water and Waste Water Management, and Tourism (MMO, 2014), where some sectors are already considered implicit or explicit in some nodes, e.g. MPAs and Aquaculture are implicit in Environmental Quality node, Nuclear Energy, Offshore Renewables, and Oil and Gas in Energy Occupation node, Surface Water and Waste Management is split to water occupation and waste discharge nodes, CCS in green technology node, etc, and some are omitted, e.g. Defence, Recreation, and Tourism are not in any node.

2.2. Equations

After having the causal loop diagram in Figure 1, we require to define the equations relating all nodes in the diagram. Several types of the equation relate two or more nodes. First type is linear relationship

\[ x_i = f_1(x_j) = a_{ij} x_j + b_{ij}, \]

between node \( x_i \) and \( x_j \) with \( a_{ij} \) and constant \( b_{ij} \) coefficients. Second type is reciprocal relationship

\[ x_i = f_2(x_j) = \frac{a_{ij}}{x_j - b_{ij}} + c_{ij}, \]

between node \( x_i \) and \( x_j \) with \( a_{ij} \), \( b_{ij} \), and \( c_{ij} \) coefficients. Third type is sigmoid relationship

\[ x_i = f_3(x_j) = \frac{a_{ij}}{1 + e^{-b_{ij}(x_j - c_{ij})}}, \]

between node \( x_i \) and \( x_j \) with \( a_{ij} \), \( b_{ij} \), and \( c_{ij} \) coefficients. Illustration of these first three types is given in Figure 2.

![Figure 2](image)

**Figure 2.** Relationship between nodes \( x_j \) and \( x_i \) can in the form of linear function (left), reciprocal function (center), or sigmoid function (right).

According to Equation (1) – (3), the first equation can produce positive and negative causal links, the second equation can only produce a negative causal link, and the third equation only produce a positive causal link. These first three types of relationships have instantaneous relation, which means that at time \( t \) value of \( x_j \) will induce the value of \( x_i \) without time delay \( \Delta t \).

Fourth type is when a node is accepting input from more than one node then these inputs should
be weighted and summed to construct an argument for the previous three functions
\[ x_i = f_4(x_j + x_k + x_l + \cdots) = f_n(w_j x_j + w_k x_k + w_l x_l + \cdots), \tag{4} \]
where \( n = 1, 2, 3 \), is referring to Eqns. (1) – (3). Weights \( w_j, w_k, w_l, \ldots \), can be normalized as follow
\[ w_j + w_k + w_l + \cdots = 1 \tag{5} \]
And the last type considers accumulative relationship that
\[ x_i(t + \Delta t) = f_5[x_j(t)] = f_n[x_j(t)] + x_i(t), \tag{6} \]
relates \( x_i \) with \( x_j \) and previous value of \( x_i \). In Equation (6) value of \( n = 1, 2, 3 \) as in Equation (4).

2.3. Mapping nodes to variables
Based on Figure 1 there are a lot of nodes that must be mapped into variables and then set which relationships they have. Variable names are defined with four letters, e.g. GDPP for Port-driven GDP, POPD for Death, PDEM for Port Demand, and should still represent the node name. A parameter \( c_{\text{DEST_SRC}} \) is used to relate the relation from SRC to DEST through Eqns. (1) – (5), e.g. \( c_{\text{GDPP_PCTX}} \) is used in
\[ \text{GDPP}(t + \Delta t) = \text{GDPP}(t) + c_{\text{GDPP_PCTX}} \times \text{PCTX}, \tag{7} \]
where \( \text{PCTX} \) is for Port Cargo Throughput. Eqn. (7) is using the fifth type of relationship between nodes as given previously in Eqn. (6).

3. Results and discussion
3.1. Parameters and output
Following parameters are used for this work unless there is some further information.

\[
\begin{align*}
\text{GTEC} &= 1; & c_{\text{ENEO GDPP}} &= 0.2; & c_{\text{PPRE PDEM}} &= 1; & c_{\text{IINV GDPU}} &= 0.1; \\
\text{GDPP} &= 1000; & c_{\text{WASD GDPP}} &= 0.2; & c_{\text{GDPU_PPKE}} &= 20; & c_{\text{INDI INFO}} &= 0.01; \\
\text{GDPU} &= 1000; & c_{\text{WATO GDPP}} &= 0.2; & c_{\text{INDO INFI}} &= 0.01; \\
\text{PCTC} &= 5; & c_{\text{WASD GDPP}} &= 0.0; & c_{\text{PINV GDPU}} &= 0.01; & c_{\text{TRAO INDI}} &= 0.01; \\
\text{POPU} &= 10000; & c_{\text{WATO GDPP}} &= 0.0; & c_{\text{PREV PCTX}} &= 0.001; & c_{\text{TRAO INDI}} &= 0.01; \\
& & c_{\text{GDPP PCTX}} &= 1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1;  \\
& & c_{\text{GDPU PCTX}} &= 1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1; \\
& & c_{\text{GDPU HRIHR}} &= 0.1; & c_{\text{GDPU_PPKE}} &= 0.2; & c_{\text{INDO INFI}} &= 0.1;
\end{align*}
\]

For now, \( b_{ij} \) in Equation (2) is almost all set to zero and the value of \( a_{ij} \) is given in the form of \( c_{\text{DEST SRC}} \). Some nodes that use Equation (6) must have predefined values, which are GDPP, GDPU, PCTC, and POPU.

Figure 3. User Interface of an in-house software developed to simulate the green port nodes using system dynamics, where the header is showing the name of the nodes.
A node can be multiplied by a factor to increase readability while its value changes during the simulation as shown in Figure 3. This factor will not affect the relation between nodes.

3.2. Comparison of without and with green technology
One of the parameters to switch between without and with green technology is \( G_{TEC} \), where values 0 and 1 are for without and with the technology, respectively. Figure 4 shows the comparison of the results between those two policies.

![Graphs showing comparison](image)

**Figure 4.** Comparison of the results without (left column) and with (right column) green technology policy, for (a)-(b) GDPP-GDPU, (c)-(d) POPU-LIFQ, (e)-(f) PCTX-PCTC, (g)-(h) ENVQ-HRIS, (i)-(j) INDI-INDO, and (k)-(l) TRAD-SHOC nodes, wherein each chart blue line uses left vertical axis and red line uses right vertical axis.
From both scenarios, without (NG) and with green (WG) technologies, we can see that the growth of population is the same as shown in Figure 4c and 4d. This result is surprising since population in-migration depends on the Urban GDP or GDPU, which is lower in NG compared to WG. Both have a similar profile for the population (increasing) and Life Quality or LIFQ (decreasing). In WG the health risk is decreasing, which is increasing birth and decreasing death, while in NG the changes are in opposite direction. This can compensate for the higher GDPP in WG compared to the NG scenario.

And for national issue of Patimban Deep Sea Port Figure 4i and 4j for NG and WG scenarios, respectively, the development of intrastate industries (industries in the same province with the port) or INDi and interstate industries (industries from all province) or INDO give a promising prediction, where INDi is increasing and INDO is decreasing, while the last is even reaching zero around eight years for NG and five years for WG. This is an advantage of the implementation of green technology to the shift of use intrastate port instead of interstate (national) port. The shift will also reduce pollution during the transportation of goods from their source to the port and also save the maintenance of interstate infrastructures, e.g. highways, which are usually defected, even destructed, by the trucks with container

In both scenarios, Environment Quality or ENVQ and Health Risk or HRIS are change in the opposite direction as expected and designed. Figure 4g and 4h show these features. And for the relation between Port Cargo Throughput or PCTX and Port Cargo Throughput Capacity or PCTC for both scenarios are shown in Figure 4e and 4f, wherein WG the PCTX are reaching the PCTC, which means more efficient compared to in NG scenario. Trade or TRAD and Shoreline Occupation or SHOC relation for NG and WG are given in Figure 4k and 4l, where the WG scenario gives about the same SHOC but with more TRAD compared to NG scenario, which also shows an efficiency.

4. Conclusion
A model to simulate the interaction between marine sectors in future Patimbang Deep Sea Port using system dynamics with in-house software has been performed. It shows that implementation of Green Technology policy gives some benefits than the conventional ones, such as the shift of the use of the interstate port to intrastate port, higher Port Cargo Throughput with similar Shoreline Occupancy, higher GDP for port and the city nearby but with relatively the same population. These results show a promising future of the development of a green port for Patimban Deep Sea Port.

References
[1] You S, Kim M, Lee J and Chon J 2018 Environ. Pollut. 242 2040
[2] Wen-Jui Tan, Chen-Feng Yang, Pierre-Alexandre Château, Meng-Tsung Lee, Yang-Chi Chang 2018 Ocean Coast. Manag. 153 131
[3] Robadue Jr. DD and del Moral Simanek R 2007 Proc.25th Int. Conf. on System Dynamics Society (Boston) vol 6 (Littleton: System Dynamics Society) p 3927
[4] Supriatna, Supriatna J, Koestoor RH and Takarina ND 2016 Procedia Soc. Behav. Sci. 227 19
[5] Moradi M, Kazeminezhad MH and Kabiri K 2020 Int. J. Disaster Risk Reduct. 49 101665
[6] Jokhu PD and Kutay C 2020 Sustainability 12 2245
[7] Isa SH, Ramlee MNA, Lola MS, Ikhwanuddin M, Azra MN, Abdullah MT, Zakaria S and Ibrahim Y 2020 Environ. Dev. Sustain. Published 16 Jan 2020
[8] Hossain MS, Ramirez J, Szabo S, Eigenbrod F, Johnson FA, Speranza CI and Dearing JA 2020 Reg. Environ. Change 20 28
[9] Li Y, Zhang X, Lin K and Huang Q 2019 Sustainability 11 5948
[10] Tuu NT, Lim J, Kim S, Tri VPD, Kim H and Kim J 2020 J. Water Clim. Change 11 514
[11] Brennan C, Ashley M and Molloy O 2019 Front. Mar. Sci. 6 360
[12] Sadek I and Elgohary M 2020 Environ. Sci. Pollut. Res. 27 5547
[13] Julian MM, Wahyuono RA, Prasetio EA and Poerbandono 2020 E3S Web Conf. 190, 00025
[14] Bala BK, Arshad FM and Noh KM 2017 System Dynamics: Modelling and Simulation (Singapore: Springer) p 37
[16] MMO (2014). Social Impacts and Interactions Between Marine Sectors. A report produced for the Marine Management Organisation, pp 273. MMO Project No: 1060. ISBN: 978-1-909452-30-5. First published August 2014.

Acknowledgments
Authors wishing to acknowledge assistance from Faculty of Social and Political Science, Universitas Padjajaran and encouragement from colleagues from Faculty of Engineering and Computer Science, Universitas Komputer Indonesia.