Indonesian Journal of Electrical Engineering and Computer Science
Vol. 6, No. 2, May 2017, pp. 447 ~ 456
DOI: 10.11591/ijeecs.v6.i2.pp447-456

Creating Model with System Breakdown Structure for System Dynamics

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Abstract

A system is developed as a set of components and subsystems. A subsystem is a smaller system inside the main system and consists of its constituent components. The continual improvement process concept is adopted in System Dynamics's model creation. New components or subsystems are identified in each cycle of the process. The interrelation between components could be changed as the time is running. The continual improvement process is an ongoing effort in identifying an ideal model. In this paper, the system is explained as the set theory for better understanding. It is emphasized that by breaking down the system into smaller entity such as components and subsystems will make the analytics process more systematic and scalable. It is called as System Breakdown Structure (SBS). At the end of this paper, the model before and after SBS are evaluated by comparing the output and the state of system.

Keywords*: system dynamics, system breakdown structure*

1. Introduction

The systems theory has served and been applicable in many branches of science [1-7]. One methodology of the system theory is the system dynamics [8]. It utilizes the model of the real system to study and understand the behavior of the system and produce a suitable approach to solve the problem on the system. At the beginning, system dynamics was introduced by Jay Forrester in 1961 [8] and continued evolving and growing significantly in understanding and resolving some of the problems in some fields of science such as economic, environmental, management, and so on. The system is evaluated from the simple one into the complex one [9] which needs more advance techniques to analyze [10].

In system dynamics, a model of system is the main topic in this methodology. Identification of the model is very crucial before running the simulation to understand the behavior of the system. The more match the model is in representing the real system, the more accurate the simulation gives the outcome. The identified model is used in running simulation with multiple scenarios, and the result describes the behavior and nature of the system. There are several reasons why the models are used. Some reasons are because that it is harder doing experiments in the real system, it is more costly to experiment in the real system and it is higher risk if the intervention is conducted into the real system [11]. But unfortunately, it's not easy to formulate the model, especially from complex real system [12]. At this moment, there is no method or technique in modeling the real system systematically. On this occasion, System Breakdown Structure (SBS) is introduced and explained to overcome the limitation of theoretical explanation in previous papers [13, 14].

2. The Proposed Method

SBS [13,14] is re-explained, but in set theory way. It is expected to give another perspective and make the modeling process easier, systematic and scalable. SBS is to accommodate the continual improvement process in understanding the complex system. The idea is to make each component of system as smaller as possible. Smaller component is more manageable in choosing which approach to handle it [15]. Identification of how to create the approach such as quantitatively and qualitatively, can be done systematically without interfering other components [16].

Received February 12, 2017; Revised May 2, 2017; Accepted May 16, 2017

As comparison, the real system G dan its models are shown in Figure 1. System G has one input and one output. To simulate the input and output of system G, the model is created and at the beginning five components {g_1, g_2, g_3, g_4, g_5} are identified in the model as the top down approach [17]. The model is not exactly the mirror of the system, but it attempts to imitate the behavior of the system. A good model minimize the difference or gaps/errors of its behavior with the real system.

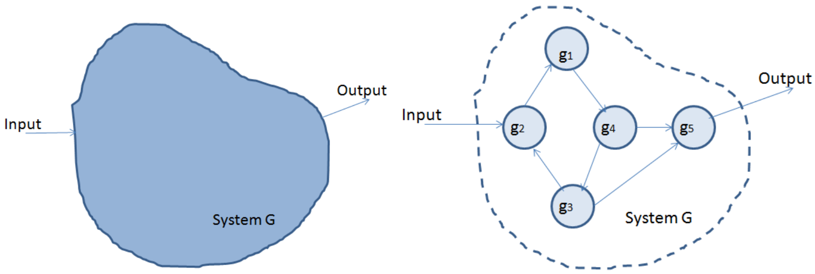

Figure 1. Real System Diagram and its Model Diagram

Development of the real system's model is a process that needs more than one cycle. It is a continual improvement process [18, 19]. The repeatable process or cycle is for improvement of each cycle [20]. In each cycle of process, the new components or subsystems could be identified and the interrelation is modified or updated. The complexity becomes reality as the system is growing. In the ongoing process, it is also possible that the component is detected and modified into several smaller components. It is called as evolution of component into subsystem. The system consists of several components or subsystems. In this paper, the component of system is the smallest part of a system. If the components can be broken down into several components, then the component term would change as a subsystem. The subsystem is actually the smaller system as part of the original system. In our case above, the g_5 in Figure 1 which has multiple components is not a component any more, but identified as a subsystem.

In system dynamics, components as smaller entities of the system are studied dynamically. By identifying components as accurate as possible, it will minimize the gaps/error between the real system and its model. Running simulation on the accurate model with few different scenarios is to obtain optimal outcome. This is explained well by [8, 16, 21-24] and other experts in system dynamics. System G is discussed in more detail to explain SBS in perspective of set theory. It consists of input and output as the impact with the interaction with other system or external environment. In our diagram (Figure 2), the notation of external environment is ~G (negation of G). System G has boundary to segregate them with the environment ~G. There is a possibility to have several components or subsystems and each of them have the relationships inside the system G. In our case, there are five components inside the system G. It is assumed that those components are the smaller entities of system G. There is no subsystem at this moment.

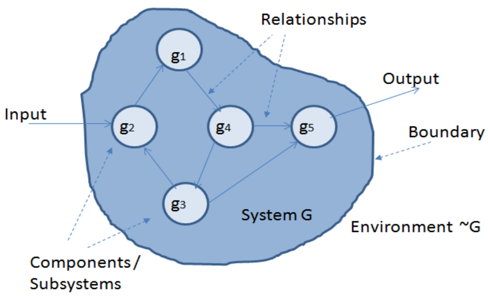

Figure 2. System G

In system dynamics, the real system is the object to be studied. As several reasons discussed before, representation of real system as a model is needed. The main difficulty in constructing a model, especially for large and complex systems is that many components and interrelations are involved. Designing a model partially, integrating each partial model and evolution of each model is an art [25]. There is no correct and wrong way in creating the model. Other researchers [26] mentioned that all models are wrong. But by understanding the approach of identifying the model, somebody can argue other approaches. SBS with continual improvement process approach is the other alternative. It consist several activities, such as below.

2.1. Understand System as a Set

At the beginning, let’s assume that the system G consists of five components (see Figure 2).

$$G = \{g_1, g_2, g_3, g_4, g_5\}$$

Each of the components has the possibility to influence other components or itself. So the total possible relationships are 25. If these relationships are represented in the form of a matrix, it will be obtained as below (Table 1). Whereas the relation R has only 2 values, the value of 1 (one) is presented as an existence of relationship and the value 0 (zero) as an absence of a relationship. It is written as relation R : G x G → {0,1}.

Table 1. Relation R Matrix of Internal System G

From	To	g_1	g_2	g_3	g_4	g_5
g_1		0	0	0	1	0
g_2		1	0	0	0	0
g_3		0	1	0	0	1
g_4		0	0	1	0	1
g_5		0	0	0	0	0

Matrix System G above (Table 1) does not represent the interaction with the system outside of G. To consider environment ~G, the input and the output originating from and toward to environment ~G are evaluated. Most of the system dynamics model are closed system, it means not to consider the input to and output from environment ~G. But for the generality of a system and anticipating the expansion of the system, the input and output of System G are considered. The matrix (Table 1) is modified by adding columns and rows of the environment ~G. NA (not applicable) is stated on the matrix to show that the interrelation between outside system is ignored. A relation correlates an output of a component/subsystem/system to an input of the other one. In general it follows $y = f(x)$, where x is the input and y is the output. The function f(x) is a function of the input x, which gives the output y. For the system G, relation function between input and output is $f_G(x) = y$, where x is the input and y is the output of the system G, as Figure 1.

If the system has several components, such as System G then each component have their own function and characteristic. For example component g_5 in system G, it has a function $f_{g5}(x_{g4\text{-}g5},x_{g3\text{-}g5}) = y$, where $x_{g4\text{-}g5}$ is input from component g_4 and $x_{g3\text{-}g5}$ is the input from component g_3 and y is the output of components g_5 which is also the output of the system G. Similarly, function $f_{g2}(x,x_{g3\text{-}g2}) = y_{g2\text{-}g1}$. If $y_{g2\text{-}g1}$ is the output of g_2 and the input to the component g_1, or it can be mentioned that $y_{g2\text{-}g1} = x_{g2\text{-}g1}$. if the relationship R has only two value, one and zero then R : G x G → {0,1}. Most of the case of system dynamics, the output from a component is always the same, such as component g_3 whereas $f_{g3}(x_{g4\text{-}g3}) = y_{g3\text{-}g2} = y_{g3\text{-}g5}$.

2.2. Identify State Condition of the System

System state condition is the condition of the system at the time t. Example the storage tank initial state (t = 0), it could be empty, full, or only 10% filled by water. Some systems will act differently even though the inputs are the same due to the difference of system state condition. Practical example is that pushing empty and full storage tank with the same efforts could give the different result. Relation function of input and output needs to consider the system state condition. In our matrix table, the state condition is represented as the input from its own components, example $x_{g1\text{-}g1}$, $x_{g2\text{-}g2}$, $x_{g3\text{-}g3}$, $x_{g4\text{-}g4}$, $x_{g5\text{-}g5}$. This is an input as well as output to a component g_i. In this case, if there is $x_{g3\text{-}g3}$, then it will the same as $y_{g3\text{-}g3}$, $y_{g3\text{-}g2}$ and $y_{g3\text{-}g5}$.

2.3. Run System Breakdown Structure (SBS)

System Breakdown Structure (SBS) is refer as the technique to identify the components, subsystems and its relations in a system, break down the subsystem into smaller components in systematic and hierarchical way and conduct continual improvement process to identify new components, subsystems and its relations. If it is identified that one or more the components are needed to be broken down into smaller ones, such as components g_5 (see Figure 3), then it is no longer referred to as a component, but subsystem so that notation changes into a subsystem G_5. It consists of three components. Therefore the subsystem G_5 can be expressed as $G_5 = \{ g_{5.1}, g_{5.2}, g_{5.3}\}$.

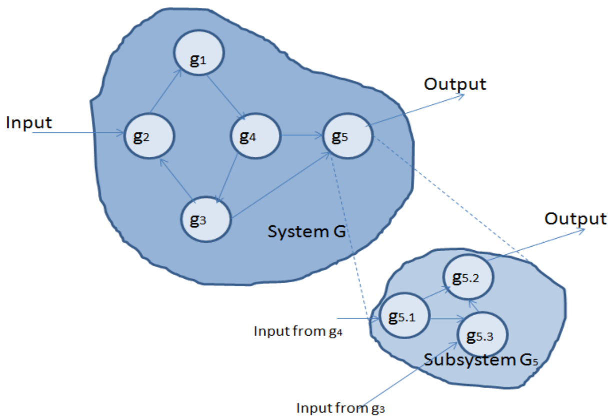

Figure 3. System Breakdown Structure of System G

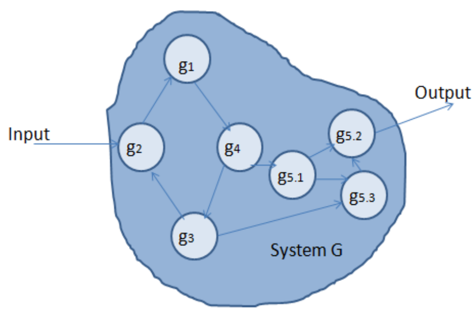

Figure 4. System G = G'

Initial number 5 is still kept in the naming of components of subsystem G_5. This will help in grouping the components in hierarchical. So the system G which was composed of five components, $G = \{g_1, g_2, g_3, g_4, g_5\}$ needs to be revised to system G'.

$$G' = \{g_1, g_2, g_3, g_4, G_5\}$$
$$= \{g_1, g_2, g_3, g_4, \{g_{5.1}, g_{5.2}, g_{5.3}\}\}$$

As the behavior is the same, System G' can be written as

$$G' = \{g_1, g_2, g_3, g_4, g_{5.1}, g_{5.2}, g_{5.3}\}$$

Each new component has its own relation function, such as component $g_{5.2}$, $fg_{5.2}$ ($x_{g5.1\text{-}g5.2}$, $x_{g5.3\text{-}g5.2}$) = y. As well as other components, such as $f_{g5.1}$ ($x_{g4\text{-}g5.1}$) = $y_{g5.1\text{-}g5.2}$. Input $x_{g4\text{-}g5.1}$ is equal to the previous input $x_{g4\text{-}g5}$ (before SBS), and $fg_{5.3}$ ($x_{g3\text{-}g5.3}$, $x_{g5.1\text{-}g5.3}$) = $y_{g5.3\text{-}g5.2}$.

2.4. Identify Multiple Input and Output (optional)

In our case $x_{g3\text{-}g5.3}$ input is equal to the previous input $x_{g3\text{-}g5}$. SBS is a tool to clarify and make more detail of the system being observed and adopt learning process to find out the accurate model. Each component has their own approach to identify their function or behavior. It is independent and has its own characteristics.

Some systems have multiple input and output. It is written as **f**(**x**) = **y** (in bold) whereas

$$\mathbf{x} = \{x_1, x_2, x_3, x_4, \ldots, x_n\}$$

$$\mathbf{f}(\mathbf{x}) = y = \{y_1, y_2, y_3, y_4, \ldots, y_n\}$$

In the system dynamics, each output of the components usually has the same value. It means $y_1 = y_2 = y_3 = y_4 = y_n$.

2.5. Identiy Fuzziness in the Relations (optional)

Relation R between a component or subsystem does not necessarily binary logic {0,1}, but it can be fuzzy logic [0,1]. The intensity of the relation between the component or subsystem are not crisp, but have a degree of influence. It is relation $R : G \times G \rightarrow [0,1]$, as the table matrix is modified by introducing r where $0 \leq r \leq 1$. In reality, the relation is very dynamics. At beginning, there is zero relation, but next time it could be changed. The relation could be growing or shrinking. The relation becomes another function. In this case, the matrix could be modified to become more general. For example that $r_{g3\text{-}g1} = 0$ at this moment (t = 0), but in the future it could be increasing to certain value.

3. Research Method

After discussing how the set theory can explain SBS, the next challenge is how to implement this theory into practical way and alignment with current technology in system dynamcs implementation. What diffrencess are between before and after SBS. Below is the result in modeling System Z (see Figure 5) by using SBS.

Let's introduce a system Z and it consists of three subsystems. $Z = \{ Z_1, Z_2, Z_3\}$.

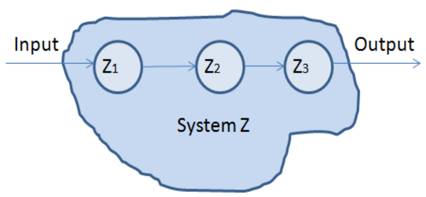

Figure 5. System Z

After the process of SBS, it is identified that each subsystem consists of another 3 components. $Z_1 = \{Z_{1.1}, Z_{1.2}, Z_{1.3}\}$, $Z_2 = \{Z_{2.1}, Z_{2.2}, Z_{2.3}\}$ and $Z_3 = \{Z_{3.1}, Z_{3.2}, Z_{3.3}\}$. It is assumed that the model of subsystem Zi is as stock and flow diagram (see Figure 6). The overall model of system Z is in Figure 7. (Note: Before running the SBS, it is assumed that the system Z is as a single storage with three times in size of subsystem Z_i).

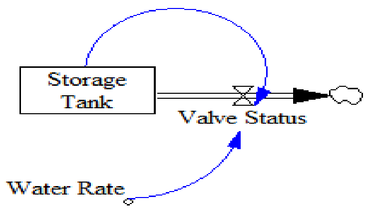

Figure 6. Model of Subsystem Zi

It is recommended that the number of the component or subsystems are consistently put after the name of the components, such as component $z_{1.1}$ (1.1), component $z_{2.3}$ (2.3) and so on. It becomes the identification of subsystem or group of components. The second step creates the table to show the equation. It recommended that the number column of the table (No.) is alignment with the identification number on the diagram. The components column is the same as the description or name of the components in the diagram. Initial column is a variable identification to represent the component in the equation column, which is used in the developing the function. Unit column is the unit of the components [13]. For example, the system Z has three subsystems and each of subsystem Z_i has three components (see Figure 7), which are Storage Tank, Valve Status and Water Rate. Table 2 is created based on system Z.

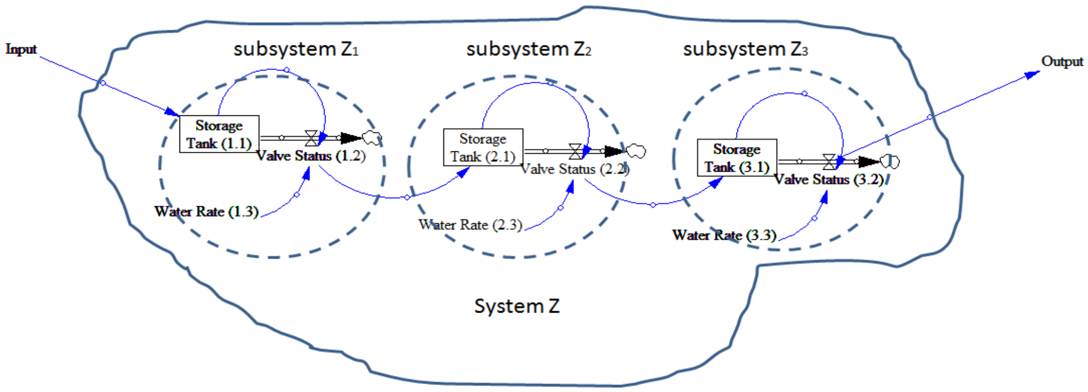

Figure 7. System Z and Subsystem Zi

Table 2. Parameters and Equations of Model after SBS

No.	Components	Initial	Equation	Unit	Remarks
1.1	Storage Tank (1.1)	ST1	100 + I – VS1	$Meter^3$	I = Input
1.2	Valve Status (1.2)	VS1	ST1 * WR1	$Meter^3$	
1.3	Water Rate (1.3)	WR1	0.1	-	10 percent
2.1	Storage Tank (2.1)	ST2	100+VS1– VS2	$Meter^3$	
2.2	Valve Status (2.2)	VS2	ST2 * WR2	$Meter^3$	
2.3	Water Rate (2.3)	WR2	0.1	-	10 percent
3.1	Storage Tank (3.1)	ST3	100+VS2 – VS3	$Meter^3$	
3.2	Valve Status (3.2)	VS3	ST3 * WR3	$Meter^3$	
3.3	Water Rate (3.3)	WR3	0.1	-	10 percent
-	Output	O	VS3	Unit	

The equation of system Z as single one (before SBS) as:

Table 3. Parameters and Equations of Model before SBS

No.	Components	Initial	Equation	Unit	Remarks
1	Storage Tank	ST	100 + I – VS	$Meter^3$	I = Input
2	Valve Status	VS	ST * WR	$Meter^3$	
3	Water Rate	WR	0.1	-	10 percent
-	Output	O	VS	Unit	

Community in System Dynamics has created an open standard which is called as XMILE [27]. This open standard is XML representation of System Dynamics model, it provides standard language, extend language, stock-flow diagram and interactive components. This XML language makes reusability of the system that was identified. Library of the system is created and easily being ported from one model to the other model. There are few ways to implement this. The common way is a standalone application, which the single PC/Server is used to collect the data and run simulation. This has been provided from the beginning of system dynamics introduction. Another way is cloud based which is still being under research [28], so the computing capacity, processing, data collection is handled by the cloud. The lower spec end point such as mobile phone can be utilized for any advanced analytics with intensive computing capacity. Combination both of them or it can be said as distributed computing [29, 30], which the computing of some components or subsystems is handled by different type of technology. In the combination concept, SBS concept and open standard XMILE are very useful.

In Figure 8, it is designed that each components or subsystems of System Z are computed in distributed way. The diagram is adopted from one of the paper about XML-based distributed communication protocol [31]. The XML RPC client initiates the methodCall to the XML RPC Server before responding with methodResponse. It could be that the source of data for subsystem Z_1 is from RDMS system, subsystem Z_2 is from Internet Crawled data and the subsystem Z_3 is from the private cloud system. Each of the sources of data has their own technique, method and system in collecting, analyzing and mining data. The model used in analyzing the system has continued to grow. Models are larger and more complex created. More data is available as in the BIG DATA era. It becomes resourceful information to identify the components and subsystems and the relationships between them.

Basically, two identification processes are needed in this modeling analytics process. First, the identification of the components and subsystems that built the main system. it is represented as function f(x)=y whereas x is input and y is output. Second, the identification of the relationships between the components and subsystems, it is also called as the structure of the system. it is the function r(t) whereas t is time, t ≥ 0 and 0 ≤ r ≤ 1. Function f(x) correlate the relationship between input and output of a component or subsystem and function r(t) correlate output one of components to the others. In practical, many researchers do not differentiate these 2 functions.

The modeling analytic process is conducted individually for each component and subsystems. For example, subsystem Z_1 (see Figure 7) is analyzed and identified that consists of 3 components. Each component is analyzed. The purpose is to discover how to get the information about the component. Component $z_{1.1}$ is the Current Water capacity of Storage Tank. This Water Capacity is fluctuated and influenced by the flow of water because of the Valve Status (component $z_{1.2}$) which is set by Water Rate (component $z_{1.3}$).

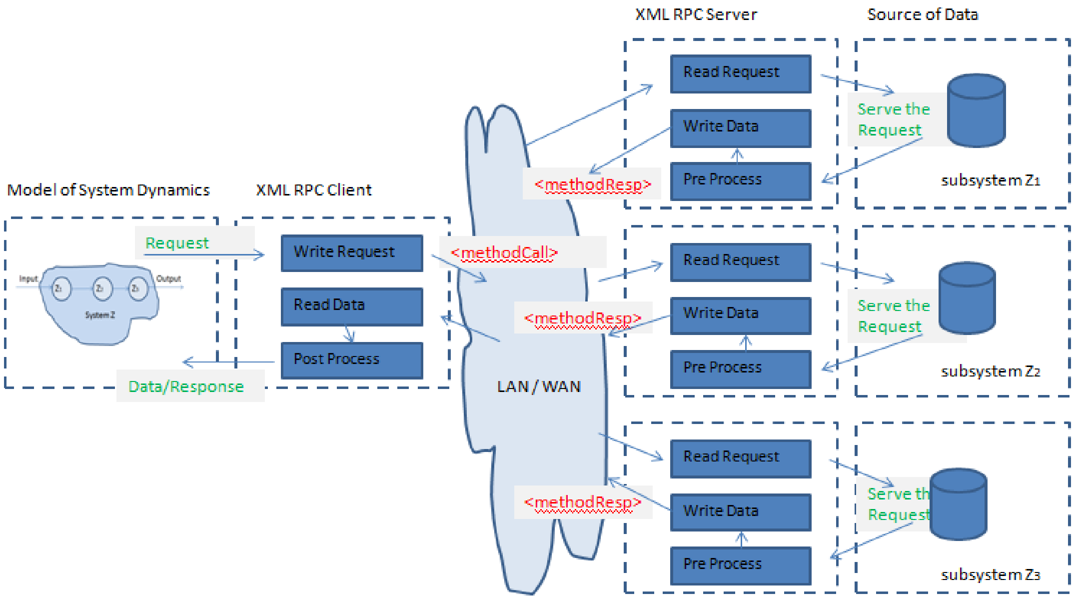

Figure 8. Distributed Computing of System Dynamics

3. Results and Discussion

Before SBS, It is assumed that system Z has a single storage tank (ST), as the state of system, to keep the water and a single valve status as the output (O). After SBS, the water is distributed into 3 storage tanks (ST1, ST2 and ST3). Average volume of water of these storage tanks is as the state of system (STSBS). The valve status 3 (VS3) is the output (OSBS). In this simulation, we will compare the output (O – OSBS) and the state of system (ST-STSBS) of both before and after SBS to learn the behaviour. There are some scenarios or cases in our simulation. The first case, no delay in all processes. The second case, there is 5 second delay between Z_1 and Z_2. The third case, there is 5 second delay between Z_2 and Z_3**.** The fourth, there is 5 second delay between Z_1 and Z_2 and also between Z_1 and Z_2. After running the simulation by comparing the differences of output (O - OSBS) and Storage Tanks level (ST – STSBS) between before and after SBS, the graphs as in Figure 9 are produced. For several cases, SBS can give more detail of the behaviour of the system but unfortunately the complexity as well. The overshoot and time to converge are two criteria in simulation to justify the performance of stability of system [20].

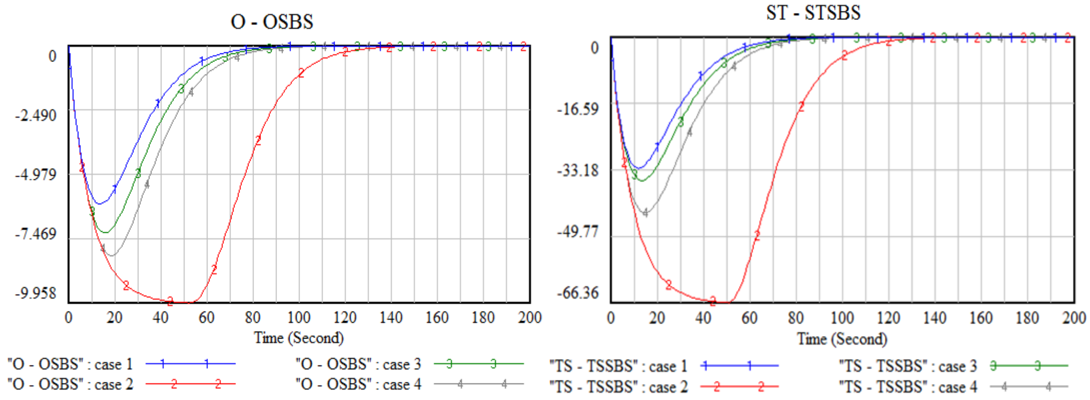

Figure 9. Output and Storage Tank Level of System Z, Input = 0 (Meter^3 vs Second)

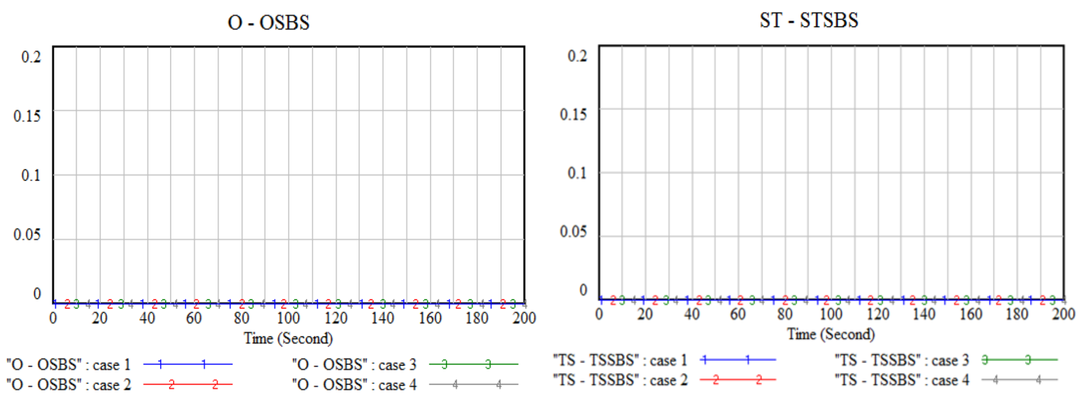

Figure 10. Output and Storage Tank Level of System Z, Input = 10 (Meter^3 vs Second)

Let's discuss the Figure 9. The case 1 gives a good result. The overshoot and the time to converge is the lowest, but not the case 2 gives the worst in all diagram. The next simulation, 10 meter^3 per second of Input flows to the system Z. Figure 10 is the result. It gives different behaviour as the first simulation (Input = 0). The Input has the same value as the output. Figure 11 is the result of input 20 meter^3. It gives almost the same behaviour as the first simulation (Input = 0) but in the reversed way.

Overall, it is clear that the transient time is about 140 seconds for the first simulation and third simulation. After finish the transient time, the output is the same as for both before and after SBS of system Z. In the second simulation, the equal value of input and output gives a non dynamic behaviour on the ouput and the state of system. SBS can help in identifying the detail of the system and its behaviour. Before SBS, the behaviour in transient time is not detected. But in the different perspective, SBS can give more tasks especially if the transient time is long and significant.

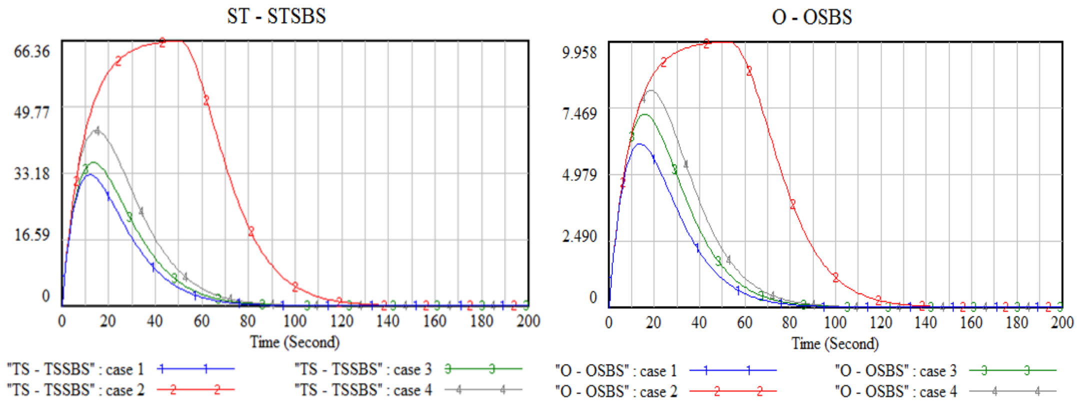

Figure 11. Output and Storage Tank Level of System Z, Input = 20 (Meter^3 vs Second)

4. Conclusion

System breakdown structure as concept has been introduced in system dynamics lately [13, 14]. The concept is a common knowledge how to interpret the system as the collection of components and subsystems. By breaking down the system or subsystems into smaller components, the identification of the component behavior and relationship between components are much easier. It is a systematic, hierarchical, and continual improvement or learning approach. Each individual component or subsystem has specific method of analytics and uses different source of data. It could be done in single PC/Server or distributed ones. Source of data could come from LAN/WAN, cloud or Internet.

SBS does not only give a better way in modeling a system but also give more details to learn the behaviour of the system. In this paper, overshoot and time to converge are two criteria to identify the consequence of SBS. If both of them are trivial and insignificant, then the side effect of SBS is nothing to be considered. Another characteristic of a system is delay. As one of the behaviour of the system, it could give impact significantly as in previous simulation such as a huge overshoot and a long time to converge.

The set theory is common theory but rephrase to suit the system dynamics in this paper. It gives another perspective of modeling the system. It is expected that this concept will create more technique and method in developing the model, especially for system dynamics. In the future, it is good to create the application software to support this SBS, continual improvement process and distributed computing. The open standard XMILE is a good first step for all these. This SBS and distributed computing is very supportive with the analytic process of huge and massive data such as BIG DATA [32, 33].

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