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DISCRETE-EVENT SIMULATION TO EVALUATE THE PERFORMANCE OF PRODUCT-SERVICE SYSTEM IN FURNITURE INDUSTRY

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ABSTRACT

Furniture industry has big opportunity in domestic market. On the other hand, it is not sustainable if furniture industry fulfill all of the demand. This situation leads to higher environmental and social impact generated from furniture industry activities. Hence, furniture industry has to improve its business which considers sustainability. Product-service system (PSS) is a business model that expected to be able to accommodate sustainability aspect in industry. However, PSS cannot ensure that sustainability aspect of an industry will be fully improved if it is implemented. So, evaluation is required to ensure the success of PSS implementation. Simulation is an evaluation tool that able to manage uncertainty that will occured in implementing PSS. This research is aimed to evaluate performance measures of both existing and PSS business model in furniture industry. There are two evaluation that will be conducted, evaluation of PSS for observed object and extension of observed object. Performance measures of the evaluation is based economy aspect (profit and lost sales) and environment (trashed furniture and CO_2 emission). The performance measures of all alternatives obtained from the simulation will be compared in order to formulate the best business model to be implemented in furniture industry. The simulation which run for 10 years shows the best scenario for observed object is scenario 2 (PoS only) with 0.895 overall performance. The best scenario for extension of observed object without UoS is scenario 2 (PoS only) with 0.804 overall performance. The best scenario for extension of observed object with UoS is scenario 6 (product, PoS, and UoS by service provider without collaboration) with 0.770 overall performance. While the best scenario for service provider is scenario 7 (collaborating UoS with manufacturer) with 1 overall performance.

Keywords: Sustainability, PSS, PSS Evaluation, Simulation

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CHAPTER 1
INTRODUCTION

This chapter consists of background, problem formulation, research objectives, research benefits, research boundaries, and report outline.

1.1 Background

One of the most important sectors in almost every country in the world is an industrial sector. According to Kemenperin (2017), manufacturing industry contributes more than 20% to the national GDP for the past five years. It makes manufacturing industry become a sector with the highest contribution to the national GDP compared to other sectors.

However, not all of the subsectors in the manufacturing industry are showing significant development and contribution to the country. One of them is furniture industry. The contribution of furniture industry to GDP of non-oil and gas industry is never exceeding 1.42% from 2012 to 2016. It makes furniture industry become one of subsector of non-oil and gas with the lowest contribution to the GDP of non-oil and gas sector. Figure 1.1 is showing the development of furniture industry in Indonesia from 2012 to 2016.

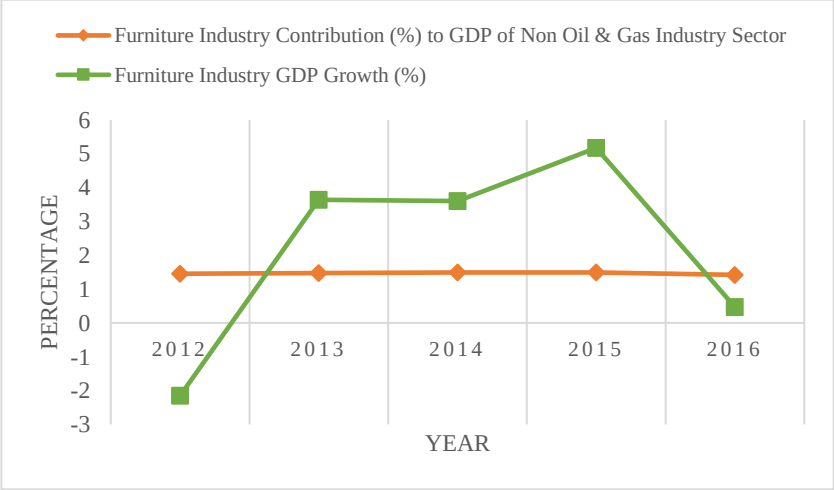

Figure 1.1 Development of Furniture Industry in Indonesia (Kemenperin 2017)

Furniture industry is also one of the potential sectors supported by government to be prioritized in the export commodity. However, the export value of furniture industry is not showing a significant increase from 2012 to 2016 instead significantly decreasing from 2014 to 2016, which means that furniture produced in Indonesia are not able to compete with furniture from other countries. It can be shown in Figure 1.2.

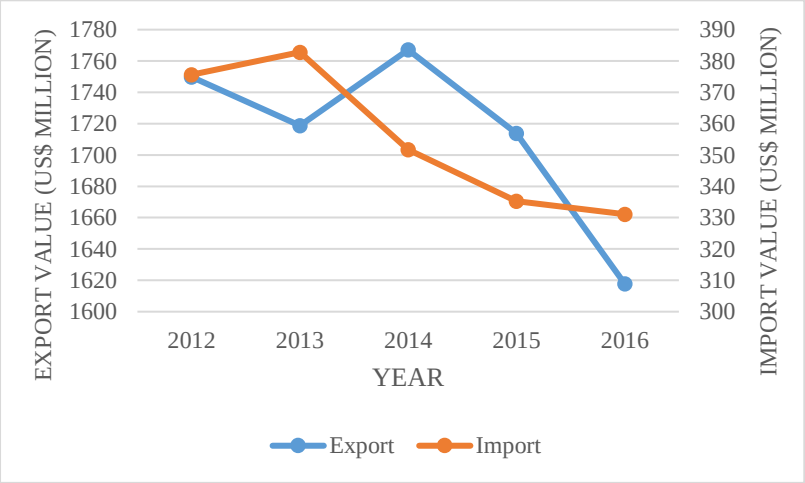

Figure 1.2 Export and Import Value of Furniture Industry in Indonesia (Kemenperin 2017)

Even though GDP contribution and export value of furniture industry are not showing significant development from 2012 to 2016, Indonesian furniture industry has a big market opportunity in the domestic market.

Furniture is one of the compulsory needs that should be fulfilled in many sectors such as households, industries, banks, hospitals, and many more. Furniture is required in every houses, offices, buildings, and plant in order to provide comfort and easiness for the user of those facilities.

The household is one of the main customers for the furniture industry. It can be a potential market for furniture industry because every living place of households is always fulfilled with furniture, especially in Indonesia which has more than 250 million population. The number of households, simple house, flat, and apartment is increasing from 2012 to 2016. It can be shown in Figure 1.3.

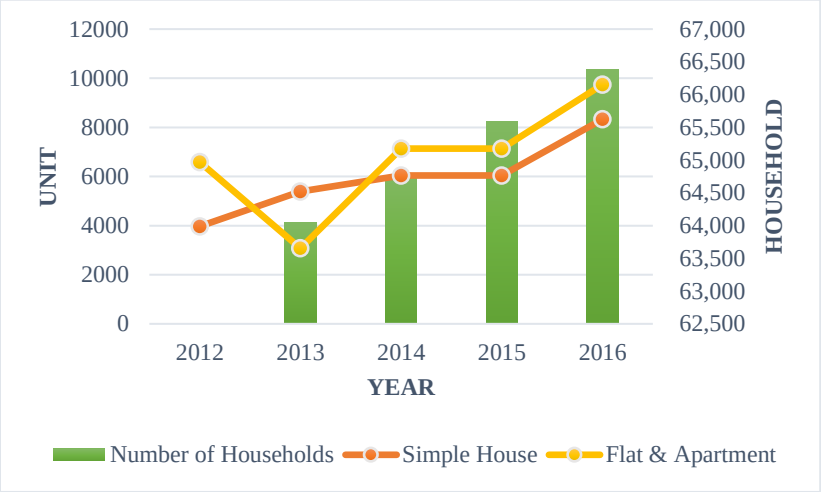

Figure 1.3 Number of Households and Living Place in Indonesia (BPS 2017)

Other sectors that become customer's of furniture industry are industries, tourism, banks, hospitals, educations, and government offices. Each office or buildings of those sectors are fulfilled with furniture in order to support each sector's activity. The number of industries, banks, hotels and accommodations, and hospitals are increasing in the previous years. The increasing number of industry, bank, hotel and accommodation, and hospital signifies that additional furniture is required to be fulfilled in offices, buildings, or plants. It can be shown in Figure 1.4.

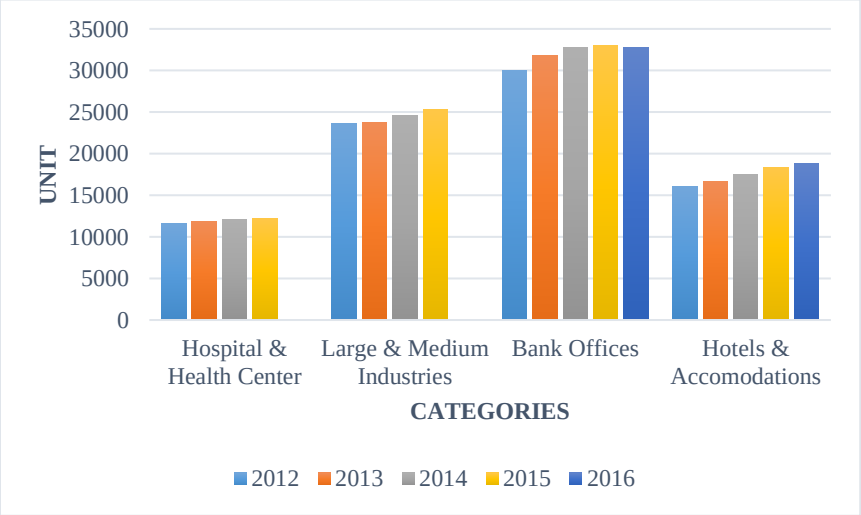

Figure 1.4 Number of Building and Office Per Category In Indonesia (BPS 2017)

With the high amount of demand that came from households, industries, banks, hotels and accommodations, and hospitals and health center can be a good chance for furniture industry to improve their profit by striving to fulfill those demand. However, striving to fulfill all of the demand is not always a good decision for the furniture industry.

Fulfilling all of the demand means that furniture industry has to produce furniture product as much as the demand. It makes there are more resources used in the production process. Every resource such as raw materials and energy used in the production process of furniture has a certain amount of environmental impact.

Those environmental impact will be felt not only by the furniture industry itself but also surrounding society and ecology. In other words, fulfilling all of furniture product's demand is not always a good decision because more environmental impact will be generated even though more profit will be gained or can be said to be not sustainable.

The occurrence of this trade-offs has to be managed by furniture industry in order to ensure that the business is sustainable. Since furniture industry is highly related with utilizing natural resources as a raw material such as woods and metals, hence it should consider more about the environment and social aspect or can be termed as a triple bottom line (Widodo et al. 2010).

In order to solve and manage sustainability issue, furniture industries should improve their business process. One of the ways is to propose business model innovation by transforming their business to include environmental as well as social targets while maintaining economic competitiveness (Barquet et al. 2016). Most of the manufacturing industry are trying to change their business orientation from a product-centric only to include services also in order to accommodate increasingly heterogeneous customer preferences, decreasing environmental impact, and achieving economic sustainability (Chen et al. 2015).

This change has generated a new style of business orientation termed as Product-Service System (PSS) (Lee et al. 2015). PSS is a new business model that enables an industry to capture and accommodate various customer needs but on the other hand also able to minimize environmental impact.

It is done in order to gain profit by providing integration of product and service. PSS can be defined as a sustainable business model by selling functionality instead of products by offering an interlinked bundle of a product and a service (Barquet et al. 2016).

The objective of PSS business model is to improve the sustainability performance of a company (Mert et al. 2014). By using this business model, a company is capable to fulfill the specific demand of the customer and reducing resource consumption while providing widely and better products and services offered (Yoon et al. 2012).

Theoretically, PSS implementation could provide several benefits both for the company, customer, and society, but its implementation cannot ensure that sustainability performance of a company will be fully improved. PSS does not always lead to sustainable solutions, PSS only offering a useful and promising concept to move in a direction of sustainability (Manzini & Vezzoli 2002).

Hence systematic evaluation is required to ensure the success of PSS implementation. Evaluating PSS implementation is an important phase that should be conducted to ensure the success of PSS. Because insufficient evaluation will allow the poor design of the business model to be implemented in practice and will cause certain damage and additional cost compensated for the future (Chen et al. 2015).

Moreover, evaluation is able to measure the performance of PSS implementation that will affect competitiveness, cost-effectiveness, and business performance of the company (Mourtzis et al. 2016). In other words, evaluating PSS can be used to measure the impact of PSS implementation towards sustainability aspect.

The concept of PSS evaluation is different from conventional evaluation problems because, in PSS, product and service activities are interacting and influencing each other. Hence, it makes a research regarding PSS evaluation resulting only a few concrete results and approaches that make it still not mature yet (Mourtzis et al. 2016).

There are two methods that can be used to evaluate PSS implementation which is a quantitative method and qualitative method. Qualitative method is required to evaluate the acceptability of PSS to customers before implementing PSS business model. Qualitative method is able to address customers' acceptance of PSS implementation by considering customers' decisions and composition of providers' offerings (Lee et al. 2015).

Quantitative method is required to get more objective analysis and reduce the probability of making different result (Yoon et al. 2012). Objective analysis is required in evaluating PSS business model that has not been implemented yet because there are uncertainties that should be considered. Source of uncertainties in the real world are randomness due to long-term behavior of implementation and fuzziness due to deficient and imprecise information (Chen et al. 2015). Since PSS implementation has long-term impact and information regarding that implementation is deficient and imprecise, then the evaluation should manage uncertainty that may occur.

Simulation is required to accommodate the uncertainty in order to get better result of the evaluation by capturing behaviour of the system. Simulation is able to solve complex problem where there are interdependencies and variability exist in the system (Harrell et al. 2004). Since activity in furniture industry is triggered based on the arrival of an order, a suitable simulation that can be used is discrete event simulation (DES). DES is a simulation where status of the system changes based on the occurrence of an event. In this research, event under consideration is arrival of furniture order.

There are several researches that have been conducted about PSS evaluation, but some of them have three main limitations. First, some of the researches did not fully including a triple bottom line in its evaluation. It discusses only customer satisfaction or environmental impact. While sustainability performance that represented by triple bottom line has not been evaluated yet. The triple bottom line has to be used as an indicator of PSS evaluation because the indicators are aligned with the objectives of PSS.

PSS is aimed to improve competitiveness, profit, customer value, and reduce negative impact to the environment (Geng et al. 2010). Sustainability of a business model can be reflected by the result of evaluation which based on the triple bottom line indicators.

Second, some of the researches use qualitative analysis which has a high probability of making a different result. For example, developing and evaluating PSS implementation with frameworks which use a scoring method to reflect participants' opinion. Whereas, most of the participant did not have any experience with a new PSS model (Yoon et al. 2012). The different participant will resulting different result. Hence qualitative analysis has a high probability of making different result.

Third, some of the researches only consider manufacturer's perspective or customer perspective. Multi-actor evaluation regarding PSS implementation has not been conducted yet. Whereas, the impact of PSS implementation in terms of triple bottom line is not only affecting manufacturer's side but also simultaneously with another actor. Because those actors are involved both directly and indirectly with furniture industry business process.

Up to now, there is no research that has been made to know performance of PSS implementation in terms of Triple Bottom Line (TBL) in Indonesia, especially in the furniture industry. Hence, it is required to conduct a research to know performance of PSS in furniture industry in terms of TBL by evaluating its implementation.

There are several actors involved in furniture industry activities such as manufacturer, service provider, distributor, retailer, third party logistics, third party repair, customer, furniture industry association, labor union, and government. Those actors are involved both directly and indirectly with furniture industry activities.

However, this research will focus only on direct relationship between furniture company with its customer. The furniture company is limited only on made to order furniture company which able to have direct transaction with their transaction without the existence of intermediaries. Hence, actors that are being considered in this research are manufacturer, customer, and service provider.

There are three types of PSS according to (Tukker 2004) which are Product-oriented Service (PoS), Use-oriented Service (UoS), and Result-oriented Service (RoS). Product-oriented Service is offering a product but with additional services such as maintenance/redesign. Use-oriented Service is offering a product to be rented rather than to be sold. Result-oriented Service is selling result of certain services.

PSS business model types that will be evaluated in this research are PoS and UoS. The last type of PSS which is RoS is not evaluated in this research since it is not relevant to furniture industry business model. RoS is not relevant with furniture industry because furniture is not a process or activity that can be accommodated with RoS. Customer must own and utilize the physical form of the furniture. Hence, only PoS and UoS is relevant with furniture industry business model.

Triple Bottom Line (TBL) aspects consist of economy, environment, and social. Since this research is focused only on evaluation of PSS implementation in direct activity of the furniture industry, then social aspect is not considered. Social aspect of the TBL is closely related with indirect activity of the furniture industry such as society acceptance and satisfaction, worker safety and health, and job opportunities. Hence, TBL that will be used as an evaluation parameter is economy and environment.

To evaluate PSS implementation in the furniture industry, one of Furniture Company in Surabaya is used as an observed object. The furniture company that will be used as an observed object is Exigo Interior. Exigo Interior is used as an observed object because they have an initiation to implement PSS business model into their business. Hence, evaluation of PSS in this research will be specified to Exigo as an observed object.

There are two evaluation that will be conducted in this research. First, evaluation of PSS performance on observed object. Second, evaluation of PSS performance for the extension of observed object. In first evaluation, UoS is not considered because observed object is MTO company. While in second evaluation, UoS is included in the evaluation by considering the existence of service provider.

1.2 Problem Formulation

Based on the background that has been stated above, there is a need to evaluate PSS by using simulation in order to know the performance of PSS implementation based on economy and environment aspect. Results of the evaluation will be used to decide the best alternatives of business model that should be implemented.

1.3 Objectives

The objectives to be achieved in this research are:

1. To develop a conceptual model of PSS implementation in furniture industry.
2. To conduct simulation of the model for existing business model and each of PSS business model to obtain its expected performance measures.
3. To formulate recommendation of a business model that should be implemented in furniture industry.

1.4 Benefits

The benefits to be obtained in this research are:

1. To know the performance of PSS business model implementation on multi-actor perspective in terms of triple bottom line aspects based on the evaluation.
2. To obtain alternatives of business model that can support triple bottom line aspects along with its considerations and impacts generated by those business model.
3. To contribute to the research field of PSS evaluation and to be used as a reference for further research.

1.5 Research Boundaries

Research boundaries of this research are defined by research scope and assumptions.

1.5.1 Research Scope

The scopes to be used in this research are:

1. PSS concepts considered are Product-oriented Service (PoS) and Use-oriented Service (UoS).
2. Actors involved in this research are manufacturer, customer, and service provider.
3. Furniture Company selected as a case study is Exigo. Exigo is the company that has been used as the case study in the previous PSS research.
4. Aspect of Triple Bottom Line used as performance of the evaluation is economy and environment

1.5.2 Assumptions

Assumptions to be used in this research are:

1. There is no change in production, shipment, installation, and repairment process in the manufacturer during the research.
2. This research is not considering the effect of the time value of money.

1.6 Report Outline

This research outline consists of several chapters. The followings are writing structure used in this research:

CHAPTER 1 – Introduction

This chapter consists of research background, problem formulation, objectives, benefits, research boundaries, and writing structure.

CHAPTER 2 – Literature Review

This chapter will explain about theory and concept used to support this research. It obtained from various sources such as a journal, article, book, and previous research. This chapter consists of explanation about sustainability, PSS, simulation, and simulation modeling.

CHAPTER 3 – Research Methodology

This chapter will explain procedures and methods used in this research. Methodology explained in this chapter will describe working flow and framework of thinking to conduct this research.

CHAPTER 4 – Conceptual Modeling, Data Collection, and Data Processing

This chapter consists of three parts. The first part is developing TBL model and conceptual model for each scenario that has been developed based on triple bottom line for each stakeholder. The second part of this chapter will show the result of data collection phase that will support data processing required in this research. The third part of this chapter is data processing to get distribution of the data to be used in the experiment using fitting distribution.

CHAPTER 5 – Simulation and Experiment

The First part of this chapter is developing simulation model. A simulation model that will be used in this research is a mathematical model. After simulation model has been developed, number of replication, verification, and validation are conducted to ensure that the model can represent the real condition of the system. After simulation model has been developed, prior to conducting the experiment, scenarios for each business model are developed in order to obtain the best result of the simulation. The experiment is performed as much as number of replication that has been determined.

CHAPTER 6 – Extension of Simulation and Experiment

This chapter will develop and simulate scenarios of business model regarding PSS for extension of observed object. Each result of the scenario will be shown and compared each other in terms of TBL. Results of the analysis will be tested and analyzed in order to determine the best scenarios that can accommodate triple bottom line aspects. The analysis will be conducted for each actor involved and for each aspect of TBL. Considerations and impacts of PSS business model also will be analyzed in this chapter.

CHAPTER 7 – Conclusion and Recommendation

This chapter consists of the conclusion of the research that will answer the objectives of this research, the suggestion that will be offered to the furniture industry, and recommendation for next research that will discuss PSS evaluation.

CHAPTER 2
LITERATURE REVIEW

This chapter explains the concept, theory, and method to be used in this research. Some concepts, theories, and methods provided in the literature review are sustainability, Product-Service System, simulation, and simulation modeling.

2.1 Sustainability

Sustainability has become an important issue since the establishment of Brundtland Report on 1987. The degradation of the environment which is mostly due to human activities becomes the reason to establish sustainable development initiation. Since then, many researches are trying to define the true meaning of sustainability. The followings are the definition of sustainability obtained from several researches.

- Sustainability can be described as corporate agendas which integrate a mix of financial and extra-financial goals, and these goals include social responsibility, environmental protection, poverty alleviation and stakeholder commitment (Gallo & Christensen 2011)
- Sustainability is recognized as a potential pathway to reorient development towards a more inclusive model, which aims to achieve a symbolic relationship among desirable economic, social, and environmental systems for both present and future generations (Cobbinah et al. 2011)
- Sustainability is about integration to develop in a way that benefits the widest possible range of sectors, across borders and even between generations (Strange & Bayley 2008)
- Sustainable development is a multidimensional concept aimed equally environment component in sustainable consumption of natural resources, protection of environmental factors, health care for the population, the social side by equality quality of life and stops poverty, economic by increasing sustainable (Strange & Bayley 2008).

- Sustainability is a development path that can be maintained indefinitely because it is socially desirable, economically viable, and ecologically sustainable (Graedel & Braden R. Allenby 2010)

It can be concluded that sustainability is a multidimensional concept which integrates three pillars of sustainability which are economic, environment, and social equally. Equally means that sustainability can only be achieved if those three pillars are considered and balanced.

Rauch (2002) described the meaning of each sustainable development pillar or can be termed as triple bottom line, which is economic, social, and environment. Economics in sustainable development should ensure the quality of life for individuals and societies. Social in sustainable development is defined as solidarization and cooperation with other communities. The environment in sustainable development is defined as conservation of natural resources.

2.2 Triple Bottom Line

Three pillars of sustainability or can be termed as triple bottom line hold an important role to the success of sustainability. The success of sustainability implementation is based on the achievement of each sustainability pillars. Office of Sustainability University of Alberta (2010) has defined the meaning for each sustainability pillars as follows:

- Environmental Sustainability

  Keeping all of earth's environmental systems in balance and ensure that consumed natural resources are able to replenish again.
- Economic Sustainability

  Human communities are able to maintain their independence and have access to the resources that they require to meet their needs.
- Social Sustainability

  Human rights and basic needs are affordable for all people to keep their families and communities healthy and secure.

There are several researches that also study the pillars of sustainability related to industrial activities. The followings are concept and point of view from several researches.

- The economic approach to sustainability is to maximize the flow of income that could be generated, but in other hand maintaining a good stock of assets (or capital) which yield the benefits (Solow 1986).
- The social concept of sustainability is people oriented which seeks to maintain the stability of social systems including the reduction of destructive conflicts (Filion et al. 1994).
- The environmental view of sustainability is focused on the stability of biological and physical system such as natural resources, pollution, and loss of biodiversity (Munasinghe & Shearer 1995).

Munasinghe (1996) in his research has illustrated the inter-linkages and interactions among three pillars of sustainability. The illustration can be shown in Figure 2.1.

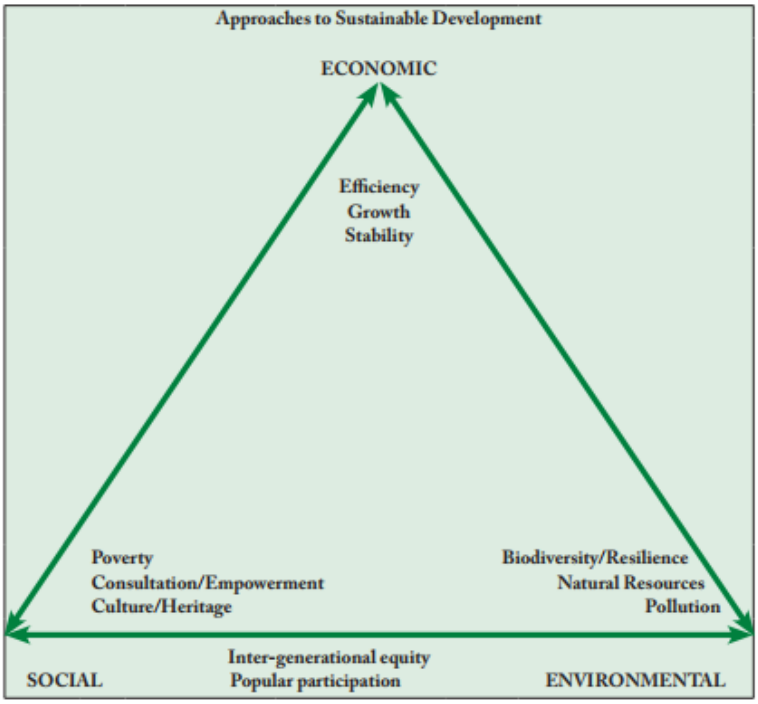

Figure 2.1 Interactions Among Pillars of Sustainability (Munasinghe 1996)

Table 2.1 Indicators and Criteria to Measure Sustainability Performance

Research	Economy	Environment	Social
(Staniškis & Arbačiauskas 2009)	Cost Reduction	Energy Consumption	Number of Working Days Lost Due to Accidents
	Investment	Water Consumption	
		Treatment Cost of Recyclable Waste	Training of Employees
(Mertens et al. 2012)	Total Revenues	Green House Gases Emissions	Total Number of Injuries
	Percentage of Sales in Markets	% of Materials Being Recycled	Total Workforce With Breakdown
	Expenditure on Research and Development	Total Weight of Waste	Total Number of Employee Turnover
		Energy Saved	Expenditure on Employee Training
(Schiehlé & Wallin 2014)	Revenue	Materials Used	Total Workforce by Employment
	Operating Costs	% of Recycled Materials	Rates of Injury and Accident
	Investment	Energy Consumption	Average Hours of Training
	Retained Earnings	Total Water Withdrawal	The effectiveness of Programs that manage the impacts of operations on communities
		Total Weight of Waste by Type	
	Financial Assistance		
		% of Products Sold That Are Reclaimed	
(Pouria 2015)	COGS	Material Consumption	Employee Satisfaction
	Operating Costs	Hazardous Materials Used	Community Trust
		Life Cycle Energy	
	Recycling Revenue	Power Use in Operation	Number of Incidents
		Product Recyclability	
	Product Disposition Cost	Emissions Generated	Lost Time Injuries
(Chen et al. 2015)	Resources Consumption Cost	Energy Consumption	Employee Satisfaction
	Operation Cost	Carbon Emission	Job Opportunities
	Penalty Cost	Waste Generation	Service Quality
(Costa et al. 2015)	Payment of PSS Offerings	Energy and Water Consumption	Safety & Health
	Total Cost of PSS Project	Waste Generation & Emissions	Working Time
		Materials Consumption	Structure of Employee

In order to know how well the performance of sustainability concept implementation, it should be measured and assessed. To get an objective measurement of sustainability performances, determined criteria/indicator should be identified. There are five researches that identify the criteria/indicator to measure sustainability performance, it can be shown in Table 2.1.

2.3 Product-Service System

PSS is a new business model that enables an industry to capture and accommodate various customer needs but in the other hand also able to minimize environmental impact in order to gain profit by providing integration of product and service. There are several researches that study the definition of PSS. Shimomura et al. (2015) in his research describe PSS as a hybrid solution that integrates products and services in order to increase value offered to the customer.

PSS can be called as sustainable business models because in PSS the companies tend to sell functionality of a product instead of the product itself (Bocken et al. 2014). By selling functionality of a product only, number of products produced can be reduced which will reduce the environmental impact of a product generated by the company and specific customer demand also can be accommodated (dematerialization).

PSS in many researches is proven to be able to facilitate sustainability pillars which are economy, environment, and social (Chen et al. 2015). In terms of economy, PSS is able to expand the business scope and establish a close and long-term relationship with the customer by providing additional services (Colen & Lambrecht 2013). In terms of environment, PSS is able to improve environmental sustainability by providing the use of the product and dematerialization of society (Sakao & Shimomura 2007). In terms of social aspect, PSS is able to increase the supply of services and compensates for the loss of jobs generated by traditional manufacturing (Baines et al. 2009).

The ultimate goal of implementing PSS is to minimize environmental impact generated from the product's consumption. It can be achieved by providing schemes of product use that can reduce consumption, improving overall resource productivity, and dematerialization (Mont 2000).

Table 2.2 Benefits of PSS for Customer and Company (Baines et al. 2007; Barquet et al. 2016)

Customer	Company	Society
• More customized offer with higher quality • Better in fulfilling customers' needs by providing functionalities and combinations of products and services • Responsibility for monitoring and end of life tasks transferred to the producer	• Improve competitive advantages and establish new market opportunities • A new alternative in terms of standardization and mass production • Increasing service elements that can improve the total value delivered to the customer • Able to access product performance data during the use phase	• Broaden access to goods and services to lower income segments • More jobs per unit of material product are created because of such labor-intensive services such as take back systems, repair, refurbishment, or disassembly • less amount of waste is incinerated or landfilled

Implementation of PSS will bring benefits for companies, customer, and society. Table 2.2 is showing benefits that will be obtained for each of them according to Baines et al. (2007) and Barquet et al. (2016).

PSS can be classified into three main categories which are Product-oriented Service (PoS), Use-oriented Service (UoS), and Result-oriented Service (ROS). Each category consists of several subcategories. Figure 2.2 is showing an illustration of PSS classification.

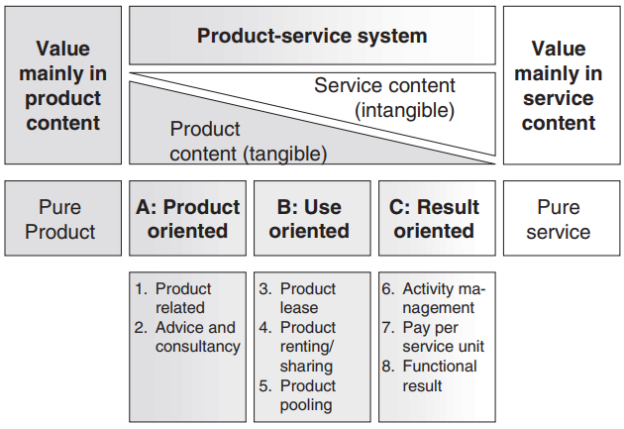

Figure 2.2 Classification of PSS (Tukker 2004)

In Product-oriented Service, focus of the company is still on the product content. In this category, ownership of the product is retained on customer's hand but added with some associated services such as maintenance, repair, reuse, recycling, training, and consulting. By implementing Product-oriented Service, companies are able to minimize costs of a whole product's lifecycle and take account design of the product which considers product end of life (Pouria 2015; Barquet et al. 2011; Tukker 2004).

There are two subcategories of PoS which are product related and advice and consultancy. In product related, company is not only selling a product but also providing additional service that can support the use phase of the product such as maintenance, financing scheme, supply of consumables, and take back agreement at product's end of life. In advice and consultancy, the company is giving advice and explanation about how to use the product in its most efficient way.

In Use-oriented Service, the company is only selling the use or the functionality of the product to the customer with modified distribution and payment system but the product is still owned by the company. By only selling the use or functionality of the product, the company is able to maximize the use of the product, fulfill the demand, and extend product's life or reuse the materials.

The use or functionality of the product can be sold in three forms which are leasing, renting/sharing, and pooling (Pouria 2015; Barquet et al. 2011; Tukker 2004). In leasing, the customer pays a regular fee for the use or functionality of the product and has unlimited access to the leased product but the company still has ownership of the product and often responsible for maintenance, repair, and control.

In renting/sharing, it has a similar system with leasing but the customer did not have unlimited access to the product because the product can be used sequentially by another customer at another time. In pooling, it has a similar system with renting/sharing but there is a simultaneous use of the product by a number of users at the same time.

In Result-oriented Service, the company is only selling result or competence of some services rather than a product. The process to achieve the result or competence of some services is owned by the company and the customer only pays for the results.

There are three subcategories of Result-oriented Service which are activity management/outsourcing, pay per service unit, and functional result. In activity management/outsourcing, some activities of a company are outsourced to a third party. So the company is only paying the result of activities conducted by outsourcing such as catering and office cleaning. In pay per service unit, the customer is no longer buys the whole product but only the output of the product based on the usage such as pay per print formulas. In functional result, the provider agrees with the client the delivery of a result. In other words, the provider is only selling result that will be obtained by the customer rather than selling a product to achieve those results (Pouria 2015; Barquet et al. 2011; Tukker 2004).

2.4 Simulation

Simulation is used to conduct numerical experiments to give a better understanding of the behavior of a system with certain conditions by designing and creating a computerized model (Kelton 2002). According to Bonate (2001), simulation is necessary to be performed if facing the following situations.

- It may not be possible to do an experiment.
- The system is complex which can’t be easily described by mathematical equations.
- It may be impossible for fiscal, time, or practical restraints to perform a large number of validation experiments on a model.
- It may be used to answer what-if questions about a system.

Simulation is able to provide insights into a complex system that cannot be provided by using other analysis techniques because simulation takes into accounts the existence of interdependencies and variability (Harrell et al. 2004).

Variability happens when the change of variable in the system cannot be predicted and expected. Interdependencies is a condition when entities are related each other. It makes behavior of an entity is influencing the behavior of other entity in the system.

Simulation has become one of the powerful tools to solve complex problems because simulation provides three main benefits for the user. First, it is versatile because able to deal with complicated problems where no analytical solution exists. Second, it is more cost-effective compared to another method. Third, it is capable to have quick and valid decision making. Fourth, it is easier to understand rather than complex mathematical equations.

Simulation is not using one exact input and one exact output. It makes simulation has to consider randomness in their usage. Simulation is using random input and resulting random output too. The model should be a valid representation of reality and consider uncertainty. It can be done by specifying probability distributions from which observations are generated and used it to drive the simulation (Kelton 2002).

Since simulation is dealing with random input and random output, most studies regarding simulation are involving more than one configuration or scenarios of the system. It is done to see how changes in design, parameters, or operation affect the performance of the system. The behavior of the system can be identified by having more than one scenarios of the system (Kelton 2002).

There are three ways to classify simulation models, it can be explained as follows (Law & Kelton 2007).

- Static vs Dynamic Simulation Models

  Static simulation model is a representation of a system at a particular time. It requires drawing random samples to generate a statistical outcome. Dynamic simulation model represents a system as it changes over time. In this model, state variables of the system are updated over time.

- Deterministic vs Stochastic Simulation Models

  In deterministic simulation model, it does not contain any probabilities. The output is determined once the set of input value has been specified. Stochastic simulation model resulting random output and must be treated as an estimation of the true characteristics of a model.

- Continuous vs Discrete Simulation Models

  In a continuous simulation model, the state of the system changes continuously over time. In a discrete simulation model, change of the system can occur only at separated points in time.

There are two types of simulation mostly used in research which are a deterministic and stochastic simulation. Stochastic simulation considers the long-term effect of random variability in the model parameters that generate an outcome of the model. Deterministic simulation is set the variability of the system equal to zero (Bonate 2001).

2.4.1 Simulation Elements and Variables

In simulation, a system consists of entity, activity, resource, control. It is used to define the who, what, where, when, and how of entity processing (Harrell et al. 2004).

- Entity

  Entity is an item processed into the system. It can be divided into three types. First, human or animate such as customers and patients. Second, inanimate item such as parts and documents. Third, intangible item such as calls, and order.

- Activity

  Activity is a task performed in the system whether directly or indirectly involved in processing an entity. It can be divided into entity processing, entity and resource movement, and resource adjustment.

- Resource

  Resource is an element of the system which conducts a process. It has a specific characteristic such as capacity, speed, reliability, etc.
- Control

  Control can be interpreted as how, when, and where activities are performed. It can be in the form of schedule, plan, and policy at the highest level. Meanwhile, it can be in the form of procedure or machine control logic at the lowest level.

In simulation, it requires an understanding of how element of the system influencing each other. In order to comprehend those relationships, system variables have to be identified. Those variables are decision variable, response variable, and state variable. (Harrell et al. 2004).

- Decision Variable

  Decision variable can be referred as an independent variable because the change of value in decision variable will affect the behavior of the system.
- Response Variable

  Response variable is used to measure the performance of the system in response to certain settings of decision variable.
- State Variable

  State variable is showing the status of the system at any specific point in time.

2.4.2 Simulation Modeling

Modeling is used to simplify a representation of a complex system in order to provide predictions or estimation of the system's performance measures of interest. The simplification of the system can be called as a model. A model is used to capture the behavior of the modeled system in order to gain knowledge and insight about the system's behavior (Altiok & Melamed 2010).

Model is usually used to evaluate the performance of the system under certain scenarios, to predict the performance of the experimental system designs, and to rank multiple designs and analyzing their trade-offs.

When the system under consideration is complex, a simulation model is preferred to be used because it is able to accommodate the unlikely event, apparent mathematical difficulties, and sufficient power to capture system's behavior.

Simulation modeling is executing a simulation program to generate sample histories. These set of histories will be used to form performance measures of the system. Simulation modeling can be used to estimate performance measures and to answer what if questions.

There are eight steps to conduct simulation modeling. It can be shown as follows (Altiok & Melamed 2010).

1. Problem analysis and information collection

   This step consists of identifying input parameters, performance measures of the system, and the relationship among parameters and variables.
2. Data collection

   Data is needed to estimate model input parameters, formulate assumptions on the distribution of random variables and model validation.
3. Model construction

   The model can be constructed and implement it as a computer program based on the formulated problem and data that has been collected.
4. Model verification

   To ensure that the model is correctly constructed, conform to its specification, and does what it supposed to do. It can be done by inspecting and comparing model code to model specification.
5. Model validation

   Model validation is conducted to examine the fit of the model to the measurements of the real system to be modeled.

The model is said to be validated if a set of performance measures of the system predicted by the model are match reasonably with their observed counterparts in the real-life system.

6. Designing and conducting simulation experiments

   A set of simulation experiments (scenarios) are designed to estimate model performance of the problem. A set of scenarios are simulated and replicated multiple times in order to reduce statistical variability.

7. Output analysis

   The result of simulation experiments is subjected to a thorough logical and statistical analysis. The analysis is conducted to determine which alternative is superior to other alternatives in terms of its performance measures.

8. Final recommendations

   The results of output analysis will be used to formulate the final recommendations.

2.4.3 Discrete-Event Simulation

Discrete-event simulation is a simulation where changes in the state of the simulation model occur at discrete points overtime as a result of events occurrence (Harrell et al. 2004). In Discrete-event simulation, the state variable changes instantaneously at separate points in time (Law & Kelton 2007). In this research, discrete-event simulation will be conducted by using Arena as a simulation software.

2.5 Previous Research

Initial research regarding PSS implementation in furniture industry has been done by Besch (2005). In that research, he is trying to identify assess barriers and opportunities when implementing PSS concept for office furniture on the European Union Market. The research is done by conducting interviews with manufacturers, customers, and experts to collect information about real-life actors' perception regarding PSS implementation.

There are six barriers identified by Besch (2005) on his research. First, financial risk for the service provider when they cannot find customers for renting. Second, competitive market conditions due to the pricing competition.

Third, there is no legislation to push manufacturer to take back their products. Fourth, characteristics of office furniture which does not seem to support renting idea. Fifth, manufacturer tend to resist the change of business model. Sixth, fashion and design are influencing customers' needs for up-to-date furniture design.

Based on the barriers identified by Besch (2005), it can be known that there are several barriers which hamper the success of PSS implementation. Hence, it requires the evaluation of PSS implementation by using simulation to accommodate those barriers. Simulation is used to manage those barriers because the occurrence of the barriers is uncertain.

First barrier can be managed by using simulation to simulate number of customers who will rent a furniture product based on the survey and observation. Second barrier can be accommodated by providing several pricing scenarios in the evaluation of PSS implementation. Based on the pricing scenarios that have been constructed, best pricing scenario can be selected that can accommodate competitive market conditions. Fourth barrier cannot be ensured yet, because market situation is changing over time. For example, the existence of apartment and trend of Small Office Home Office (SOHO) nowadays can be an opportunity for furniture industry to rent their product to the user of apartment and SOHO because needs of apartment and SOHO user in terms of furniture is different with needs of conventional house user. Development of market situation and business resulting customer need varies and change over time. Fifth barrier is also cannot be ensured yet, instead the development of market situation and business push the manufacturer to change their business model in order to compete in the market.

Another research regarding PSS implementation on furniture also has been done by Park et al. (2016). In that research, PSS concept to handle unfulfilled or insufficiently considered customer needs is generated. The concept is generated by conducting three approaches.

First, identifying customer general needs that have been fulfilled by existing PSS. The general needs are based on the PSS lifecycle which are purchase, use, and disposal phase. Second, generating PSS ideas by mapping the existing PSS onto Business System Evaluation Patterns (BSEP).

There are eight BSEP used which are customer expectation, customer purchase focus, sense interaction, increasing transparency, connections, controllability, reducing human involvement, and design point. Third, selecting PSS ideas that can meet the unfulfilled or insufficiently general needs based on the linking matrix. The result of this research is proposing new ideas for each BSEP.

General needs on the PSS lifecycle identified by Park et al. (2016) can be used as a reference to model PSS implementation in the furniture industry. General needs are classified into purchase, use, and disposal stage. General needs can be used to identify what may happen during entire PSS lifecycle.

Research in terms of PSS in furniture is also conducted by (Costa et al. 2015). In that research, pilot take-back scheme is designed and assessed using LCA. Material and information flow for PoS and UoS are constructed by considering the existence of manufacturer, end customer, dealer, and social enterprise. To assess sustainable PSS efficiency, indicators for the PSS assessment are identified and classified into finance, resources, and people for both customer and company. The LCA is conducted for three scenarios which are implementation in 5 years, 10 years, and 15 years. The assessment is conducted for three scenarios to measure performance of the pilot take-back scheme in different scenarios.

In that research, material and information flow for the pilot case and indicators for the assessment is constructed and identified. It can be used as a reference to be used in this research. Material and information flow for the pilot case can be used to construct TBL model in this research which contains multi-actor perspective. Some indicators in that research can be used as a performance measure for evaluation of PSS implementation in this research. Table 2.3 will summarize previous researchers that have been reviewed.

This research has the same observed object with Afiatna (2016) which is furniture company. Afiatna (2016) on her research is designing and evaluating PSS implementation. The design of PSS is resulting blueprint of PSS to be implemented.

Evaluation is conducted by using qualitative evaluation which based on the results of the survey to compare existing business model with PoS business model. The evaluation is resulting product service efficiency for each business model. The results are PoS business model has better efficiency compared to the existing business model, and PoS business model has a better growth rate in terms of customer preference compared to existing.

PSS blueprint constructed by Afiatna (2016) can be used as a reference to construct a business model of PSS in furniture industry. There are two blueprints constructed in this research which are Product-oriented Service blueprint and Use-oriented Service blueprint. The blueprint is showing the whole activity in the business starting from design, production, use, and disposal phase.

Yoon et al. (2012) on his research is evaluating PSS implementation by using both quantitative analysis and qualitative analysis on both provider and customer side. The quantitative analysis used in his research is simulation to evaluate relationship to current competitive providers. The qualitative analysis is conducted by having an intensive survey of potential customers.

The indicators used for provider side are macro effects represented by CO2 emission, economic feasibility, technological feasibility, political feasibility, and relationship to competitors. For customer side, the indicators used are expected value, intention to adoption, and preferred use of service. Each indicator are evaluated and analyzed to know the performance of PSS implementation for each side.

Evaluation of PSS implementation done by Yoon et al. (2012) is showing complete methodology to conduct an evaluation of PSS implementation by considering customer and provider's side and formulating conceptual model of car-sharing service simulation. That methodology and conceptual model can be adapted to be used in this research to conduct an evaluation of PSS implementation in furniture industry by considering multi-actor perspective.

Chen et al. (2015) on his research is evaluating PSS in order to know the influence of TBL towards implementation of PSS business model. In that research, type of criteria and aspects of TBL is identified for each evaluation criteria.

There are three types of criteria which are deterministic variable, fuzzy variable, and hybrid uncertain. The result of that research is to determine whether criteria have influence or not towards its TBL. While this research is evaluating PSS implementation in order to know the performance of each PSS business model in terms of TBL.

This research is compiling several criteria in existing PSS sustainable evaluation from several journal articles. The compilation is consist of economic criteria, environments criteria, social well-being criteria, PSS characteristics, and contribution for each journal article. Some criteria compiled by Chen et al. (2015) can be used as a performance measure in this research to evaluate PSS implementation in furniture industry. Table 2.4 will summarize previous researches that have been reviewed.

However, there is no research has been made to evaluate PSS implementation in terms of Triple Bottom Line (TBL) on multi-actor perspective. In this research, evaluation of PSS will be conducted based on economic, environment, and social aspect to obtain its expected performance measures by considering the perspective of manufacturer, customer, society, and service provider.

This research is a continuation of several previous researches thas has been conducted in PSS research field. Those researches are in the field of PSS design, risk, and evaluation. Zaman (2016) is designing PSS on commercial vehicle manufacturer by considering customer and manufacturer actor. Partiwi (2017) is designing Use-oriented Service on commercial vehicle manufacturer by considering manufacturer, customer, and service provider actor. Christ (2017) is analyzing risk of implementing PSS on commercial vehicle manufacturer by considering manufacturer and customer actor.

Table 2.3 Summary of Previous Research regarding PSS in Furniture

Parameter	Previous Research		
Topic	PSS in Furniture	PSS in Furniture	PSS in Furniture
Type	Journal Article	Journal Article	Journal Article
Author	(Besch 2005)	(Park et al. 2016)	(Costa et al. 2015)
Title	Product-service systems for office furniture: barriers and opportunities on the European market	Generating New Product-Service System Concepts Using General Needs and BSEP	Sustainable Product-Service Systems For an Office Furniture Manufacturer: How Insights From a Pilot Study Can Inform PSS Design
Object	Office Furniture	Furniture	Office Furniture
Methods	Survey, Interview	General Needs, Business System Evolution Patterns	Life Cycle Assesment
Output	Barriers and Opportunity in Implementing PSS	PSS Concept to Handle Unfulfilled or Insufficiently Considered Customer Needs	Design and Assesment of the pilot take-back scheme

Table 2.4 Summary of Previous Research regarding PSS Evaluation

Parameter	Previous Research		
Topic	PSS Design and Evaluation	PSS Evaluation	PSS Evaluation
Type	Master Thesis	Journal Article	Journal Article
Author	(Afiatna 2016)	(Yoon et al. 2012)	(Chen et al. 2015)
Title	Design and Evaluation of Product-Service System in Furniture Company	An evaluation method for designing a new product-service system	PSS solution evaluation considering sustainability under hybrid uncertain environments
Object	Furniture	Car Sharing	Car Rental, Crane
Methods	Fuzzy-AHP, Multi-layer QFD, Qualitative Evaluation	Simulation, Qualitative Analysis	Fuzzy Simulation
Output	PSS Blueprint, Product Service Efficiency	Evaluation results of car-sharing service based on provider and customer side	How to deal with uncertain factors when measuring sustainability criteria

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CHAPTER 3
RESEARCH METHODOLOGY

This chapter consists of the flowchart of research methodology and explanation about all phases conducted in this research so that the research could be done systematically. The research methodology contains preparation phase, modeling phase, data collection phase, data processing phase, analysis and interpretation, and conclusion and suggestion.

The flowchart of this research methodology is shown in Figure 3.1.

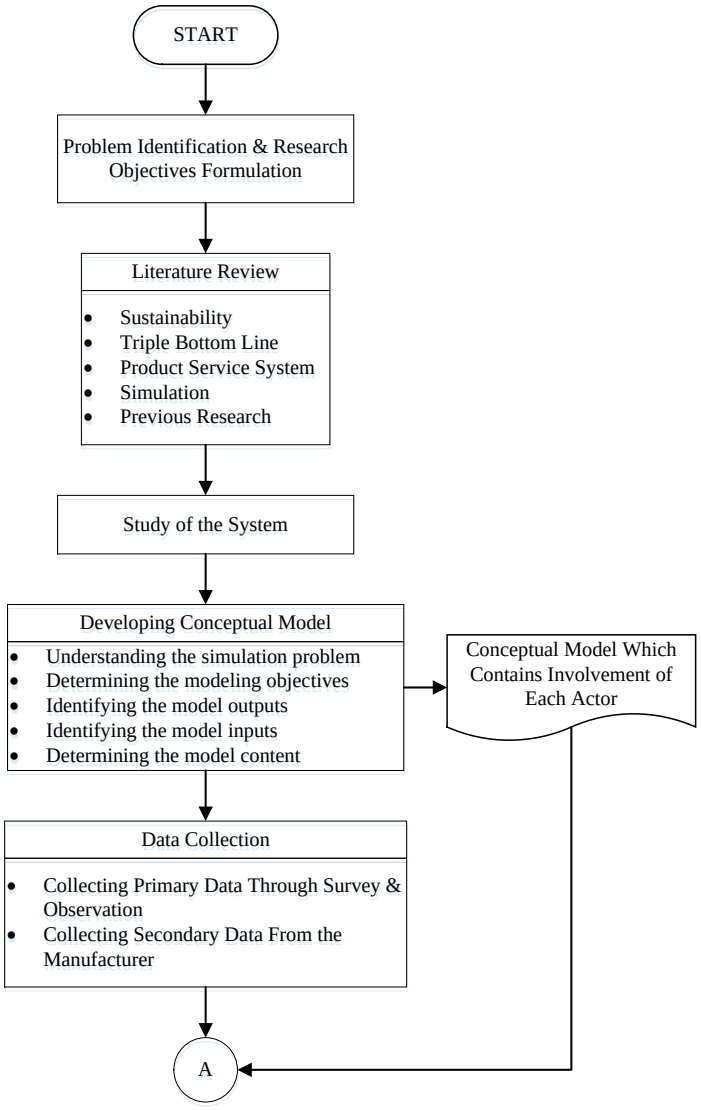

Figure 3.1 Flowchart of Research Methodology

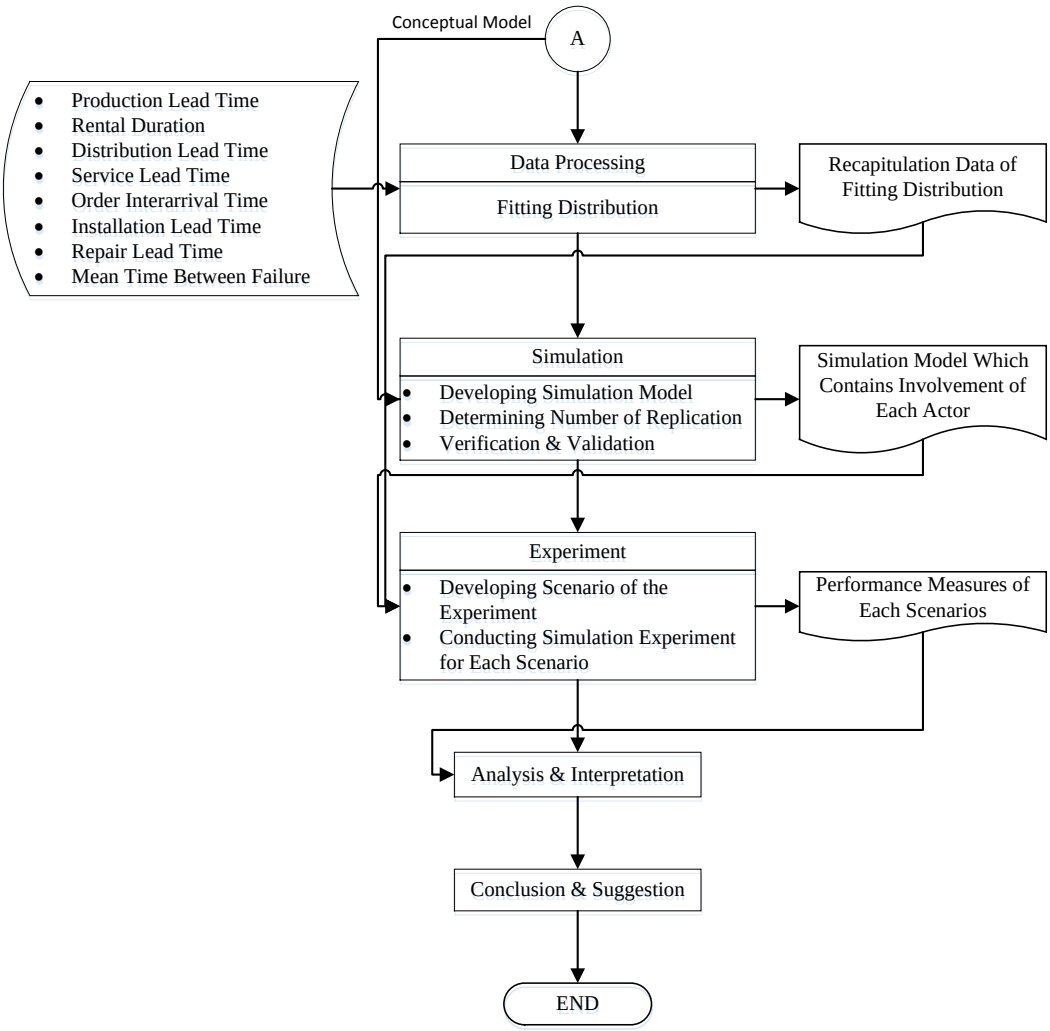

Figure 3.1 Flowchart of Research Methodology (Continued)

3.1 Problem Identification and Research Objectives Formulation

Problem identification is done to know and understand problems exist regarding the topic chosen. Based on the problem that has been identified, research objectives can be formulated to determine the outcome of the research. Problem identification is done by reviewing and evaluating previous research regarding PSS implementation and observation about existing condition of the furniture industry.

Problem identified is PSS implementation has not been proven able to accommodate all aspects of the triple bottom line yet. Hence, it corresponds with the objective of this research which is to evaluate the performance of PSS and its impact in terms of triple bottom line if it is implemented.

3.2 Literature Review

Literature review is conducted in order to support research processing and solving the identified problem. It can be done by finding, collecting, and reviewing relevant concept, theory, and method regarding the topic and the problem. Reviewed literature in this research is a literature which corresponding with sustainability, triple bottom line, Product-Service System, simulation, and discrete-event simulation. Those literature are obtained from various sources such as journal article, book, undergraduate thesis, master thesis, and website.

Besides reviewing literature required to support research processing and solving an identified problem, literature review is also reviewing previous research that relevant to chosen topic and problem used in this research. It is done to determine research position in this research compared to previous research.

3.3 Study of the System

Study of the system is conducted to identify elements involved in the system and characteristics of the system. The system of this research is furniture industry. Elements identified are system element, system variable, and performance measure of the system.

System element consists of entity, activity, resource, and control. The following is system element of this research.

1. Entities of this system are customer and order.
2. Activities of this system are production, service, renting, shipment, installation, and furniture usage.
3. Resources of this system are machine/equipment, worker, and vehicle.
4. Controls of this system are order processing system, production process flow, service scheme, renting scheme, and operational hour.

System variable consists of decision variable, response variable, and state variable. Table 3.1 is showing system variable of this research.

Table 3.1 System Variable of this research

Decision Variable	Response Variable	State Variable
Production Capacity	Production Rate	Number of Queued Order
Shipment Capacity	Order Queuing Time	Number of WIP
Service Capacity	Service Lead Time	Number of Finished Order
Renting Initial Inventory	Shipment Lead Time	Renting Inventory Level
ROP of Furniture for Renting	Energy Consumption	Furniture Idle Time

Performance measure is used to determine how well the system works under stated condition. In this research, performance measure of the system is based on TBL aspects.

Table 3.2 Performance Measure of the System

TBL Aspect	Performance Measure
Economy	Revenue
	Cost of Production
	Lost Sales
Environment	Electricity Consumption
	Carbon Emission
	Number of Trashed Furniture

3.4 Developing Conceptual Model

Prior to developing a conceptual model, TBL model is constructed first since this research is on meso scope of the furniture industry. TBL model contains interaction among actor in furniture business process. It is used to mapping the flow of product, service, and information towards TBL aspects. Interaction among each actor and trade-off between each indicator can be shown in TBL model.

Conceptual model generation is the abstraction of a simulation model from the part of the real world. It is used to simplify the real system and make assumptions about what is not known about the real system. In this research, conceptual model that will be used is flowchart. The flowchart is used because the system is following the discrete event and having a sequence of process on it.

There are five activities required to generate the conceptual model, it can be shown as follow (Robinson 2011).

- Understanding the simulation problem
- Determining the modeling and general project objectives
- Identifying the model outputs (responses)
- Identify the model inputs (experimental factors)
- Determining the model content (scope and level of detail).

The conceptual model constructed is showing the proposed business model to be simulated in this research. The constructed conceptual model is also showing the involvement of multi-actor in this research which are manufacturer, customer, and society.

The first conceptual model is for Product-oriented Service. This model is providing a conventional model where the customer can buy the product and own it but with additional service such as redesign/maintenance for the customer. The second conceptual model is Use-oriented Service scenario. This model is selling functionality of the product rather than selling the physical product by providing the rental system. In this system, the customer can rent the product for certain conditions agreed for certain period of time but the ownership of the product is still on the provider's hand.

3.5 Data Collection

Data collection phase is carried out to collect real data which can capture condition of an existing system in order to support data processing and analysis in this research.

The first step of data collection is to identify required data of the research. The data can be obtained by observing the company, doing an interview with the manufacturer, and historical data. In simulation, there are three types of data that needed to be collected, which are structural data, operational data, and numerical data. Table 3.3 is showing those data that will be needed in this research.

Table 3.3 Structural, Operational, and Numerical Data of This Research

Structural Data	Operational Data	Numerical Data
Furniture Order	Production Flow	Order Arrival
Furniture's Failure	Service Flow	Production
-	Shipment Flow	Shipment
-	-	Service
-	-	Furniture's Failure

3.6 Data Processing

In data processing, data that has been collected is processed to get distribution of the data by conducting fitting distribution. In this research, fitting distribution is conducted by using Input Analyzer software to obtain the possible distribution of the data. Those data are demand and product preference of the customer, production lead time, service lead time, rental duration, customer willingness to wait, distribution lead time, and order inter-arrival time.

3.7 Simulation

After developing a conceptual model, data collection, and data processing, the simulation model can be constructed. The simulation model is constructed based on the logic of conceptual model and real-world system. The logic of conceptual model and the data is inserted into Arena software to construct the simulation model. Simulation model is constructed to generate an output of the simulation which contains the involvement of each actor.

The output of the simulation is the expected performance of each business model in terms of aspects of the triple bottom line which are economy and environment aspect. Each aspect of TBL consists of several indicators that will be used as a performance measure for each actor to be evaluated.

The simulation will be repeated for several times in order to capture the behavior of the system during its implementation. The number of repetition has to be determined by calculating number of replication required to ensure that the simulation is able to represent the real system.

Before conducting the experiment, the simulation model has to be verified and validated. Verification is required to ensure that the simulation model has been accordance with the logic of conceptual model that has been constructed and the actual process flow. It can be done by checking and auditing whether the simulation model has been accordance with the conceptual model or pressing F4 button in Arena software for debugging.

Validation is carried out to ensure that the simulation model is able to represent the real condition. It can be done by comparing results of the simulation model with its real system by using statistical analysis. The simulation model is said to be valid if the result of simulation model has no difference with its real system.

3.8 Experiment

Subsequent to data processing, different scenarios of PSS business model are developed to be simulated. Each scenario will be compared each other to determine the best scenarios based on the simulation. The scenarios are developed based on the variables and variation of each business model.

There are three alternatives of business model that will be evaluated, which are existing business model, Product-oriented Service, and Use-oriented Service. Product-oriented Service and Use-oriented Service are the proposed business models to improve the performance of the company in terms of triple bottom line. The change from existing business model to the proposed business model is in terms of business orientation to be implemented. Existing business model is producing furniture and sell it conventionally.

PoS is producing furniture just like existing business model but with additional services such as maintenance/redesign. UoS business orientation is different with existing and Product-oriented Service business model. In UoS, the furniture is produced to be rented, not to be sold.

There are two possible alternatives in UoS. First manufacturer takes a role as a service provider. Second, the manufacturer takes a role as an intermediary of the service provider

After the scenarios have been developed, the experiment of the simulation can be performed. The experiment is performed on the existing business model scenario and followed by the other scenarios. The experiment then replicated continuously as much as number of replication that has been determined in order to obtain response variables of each scenario. After obtaining results for each scenario, the results are compared each other in order to determine the best scenarios in terms of TBL.

3.9 Analysis and Interpretation

This step is carried out to analyze and interpret the result of an experiment for each business models which are an existing business model, Product-oriented Service, and Use-oriented Service. The expected performance measures of each scenario in terms of TBL will be compared each other.

The results of the simulation will be compared for each actor and for each aspect of TBL. The comparison is aimed to know business model that can accommodate all aspects of the triple bottom line. There is a probability where trade-off occurred in terms of TBL among alternatives, hence it requires analysis to know in which condition PoS or UoS is the most suitable alternatives. The analysis and interpretation are also used to prove whether implementation of PSS is able to accommodate sustainability issues better compared to existing business model or not in the furniture industry.

3.10 Conclusion and Suggestion

Based on the analysis, it can be concluded which business model that should be implemented in furniture industry that can accommodate all aspects of the TBL. Another conclusion is an evidence whether PSS business model better than a conventional business model or not in terms of triple bottom TBL. Hereafter, it will be given a suggestion and feedback that will be useful for further research regarding this topic.

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CHAPTER 4
CONCEPTUAL MODELING, DATA COLLECTION, AND DATA PROCESSING

This chapter explains company profile of the observed object, conceptual model development, data collection, and data processing of this research. Conceptual model, collected data, and processed data will be used on both evaluations of observed object and extension of the model.

Company profile section describe company overview consist of vision, mission, customer segmentation, and product segmentation. General overview regarding business process of the observed object is also explained in this section.

In conceptual model development, conceptual model to be used in the evaluation are constructed. The conceptual model consist of interaction model among actors involved in the evaluation, and detailed conceptual model for each relationship which relates with Product-service system.

In data collection, several data required for both simulation and simulation are collected such as furniture's order component, furniture's failure, furniture's business process flow, numerical data obtained from observed object, and numerical data obtained from observation.

In data processing, there are several approach to process the data such as electricity consumption calculation, renting price calculation, selling price calculation, failure data processing, and fitting distribution.

4.1 Company Profile and System Description

This subchapter explains about company profile of the observed object and description of the system under consideration in this research.

4.1.1 Company Profile

Observed object is one of the companies that focused on interior design service and furniture production such as household furniture and public space furniture. Observed object is striving to have a good material selection, thorough production process control, and precise scheduling.

Observed object is committed to be the best partner for their customer by providing optimum service for delivering a product with the best quality. Customer easiness and satisfaction are the main objectives of Objectives in running their business process.

Observed object has wide customer segmentation consists of household, office and commercial use, school, health center, exhibition, and store. In order to fulfill customer satisfaction, Observed object provides a wide variety of product such as bedroom, living room, kitchen set, office furniture, and etc.

The increasing market competition, especially in the furniture industry, makes Observed object strive to develop their business process to compete in the market. One of the ways is by implementing PSS in their business model.

4.1.2 System Description

Currently, the manufacturer is working based on MTO (made to order) system. The whole process of the company will be operated only if triggered by the arrival of an order. In this research, there are three basic system that will be evaluated which are existing model, Product-oriented Service model, and Use-oriented Service model.

This research is not only focused on an observed object which is Exigo only, but also extension of observed object. Hence, this research will conduct two evaluation. The first evaluation is conducted to measure PSS performance on Exigo. While the second evaluation is conducted to measure PSS performance for the extension of observed object.

In existing model, the manufacturer is selling loose furniture to their customer. In general, the flow of existing model consists of receive order, consultation, drawing, propose the offering, production process, shipment, and usage by the customer. Existing model is involving two actors which are manufacturer and customer.

Product-oriented Service is selling furniture with additional service provided by the manufacturer. It has similar flow with the existing model, however, request from the customer after selling such as repairment can be accommodated by the manufacturer.

Use-oriented service is rent the furniture to the customer for certain period of time with certain terms of condition. In general, the flow of Use-oriented service consists of receive order, selecting furniture and determining renting duration, shipment of the furniture, usage by the customer, pick up the furniture from the customer, and treatment of used furniture. In this model, service provider who rent the product has to purchase or request the furniture to be rented to the manufacturer. It makes this model is involving three actors which are service provider, customer, and manufacturer.

4.2 System Characteristics and Limitation

After conceptual model has been developed, there are several system characteristics and limitation that will be applied in this research. System characteristics and limitations are needed because the model has to work under particular condition that has been stated at its initial stage. Characteristic and limitation of the system can be shown as follows :

- Entity of the simulation is order which consists of one or certain quantities of furniture.
- When an order is having a failure, then all furniture contained on that order will be broken.
- After reaching furniture's end of life, customer will reorder to the manufacturer again for the same amount of furniture type and quantity composition with its initial order.
- Repairment of the furniture is adopting "as good as new maintenance" rules. Every repairment will return condition of the furniture to its initial state.
- There are no multiple failures occurred at the same time. Each failure will be directed to only one type of failure mode.
- Additional percentage of the selling price for PoS is applied to all types of furniture.

- In UoS, a customer can rent only one unit of furniture for each furniture's type.
- There is no extension of renting duration.
- In UoS, customer is willing to wait if furniture that will be rented still unavailable yet.
- In UoS, if furniture's owned by the company is less than minimum inventor level for each type or there is no furniture available to be rented for each type, company will request or purchase for new furniture to be produced.

CHAPTER 5
SIMULATION AND EXPERIMENT

This chapter will explain about simulation model development, setting up the simulation, simulation output analysis, performance measure development, scenario development, and experiment.

In simulation model development, simulation model is constructed based on conceptual model that has been developed. The simulation model has to be accordance with conceptual model in order to represent real condition of the system.

In setting up the simulation, several aspects required for the simulation are identified such as data input, user-specified data, assumption of the simulation, and simulation duration.

In simulation output analysis, there are several aspects required to be analyzed in order to enhance accuracy of thee simulation output. It consist of determining number of replication, verification, and validation.

In performance measure development, performance measure to be used as parameter of evaluation are developed based on economy and environment aspect. Performance measure of economy aspect consist of revenue, total cost, and lost sales. While performance measure of environment aspect consist of number of trashed furniture ad carbon emission.

In scenario development, several scenarios regarding Product-service System which relates with furniture industry are developed. There are three scenario developed to be evaluated in this section.

In experiment, three scenarios that has been developed are simulated in order to obtain each performance measures that has been defined in performance measure development. After obtaining peformance measure for each scenario, the results for each scenario is compared each other in order to formulate the best scenario that will be suggested to be implemented in furniture industry.

5.1 Simulation Model

In simulation model development, simulation model is constructed based on conceptual model that has been developed. The simulation model has to be accordance with conceptual model in order to represent real condition of the system.

5.2 Setting up the Simulation

Before running the simulation model that has been developed on 5.1, there are several setting for simulation that requires to be defined. The settings are user-specified data, assumption, and simulation duration.

5.2.1 User-Specified Data

After utilizing data input in the simulation model, the simulation can be performed. Running the simulation model in Arena software is resulting several aspects regarding the system. In default, running simulation in Arena is resulting information regarding entity, queue, resource, and process of the system. However, certain user-specified information regarding the system has to be defined first. Defining user-specified information is needed in order to comply with the objective of the simulation.

5.2.2 Assumption

There are several assumptions that will be applied in this simulation, the assumptions of this simulation consist of :

- Workers, machines, and raw materials are always available when processing an order.
- There are no failure of machines or equipment utilized by the manufacturer.
- Furniture capacity of the vehicle for shipment is infinite.
- Revenue of the sales is gained after order selection has been done by the customer.

- Service process time for major failure is already including time for movement to the spot, pick up furniture to the manufacturer, repairment, shipment and installation after repairment.

5.2.3 Simulation Duration

There are two types of simulation according to its termination condition, which are terminating model and non-terminating model. This simulation will apply terminating model because it will be operated under certain period of time or condition. Period of simulation or can be termed as simulation duration or replication length tells how long simulation is going to be operated. By using lifetime period of furniture as simulation duration, furniture end of life and long-term performance of the system can be shown on the simulation.

5.3 Performance Measure Development

Running the simulation model in simulation software is resulting several outputs and statistics. However, there will be only some parts of the outputs and statistics which comply with objective the simulation. Objective of simulation in this research is evaluating performance of both existing and PSS model in furniture industry in terms of TBL.

Hence, there are some parts of the outputs and statistics that will be specified as key performance measure of the simulation. Each key performance measure will be related to economy and environment aspect.

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CHAPTER 6
EXTENSION OF SIMULATION AND EXPERIMENT

This chapter will show scenario development and experiment for extension of observed object. The difference between simulation for observed object and extension of observed object is on order preference and business model that will be developed.

On simulation for observed object, order preference of the customer is based on sales historical data. It makes variation of order that will be generated is limited only on that combination. Business model that is developed on simulation for observed object only limited to existing business model and Product-oriented Service.

On simulation extension of observed object, order preference of the customer is not limited to sales historical data. Order preference will be generated randomly based on frequency of occurrence for each type of furniture. While business model that will be developed is not limited only on existing model and Product-oriented Service model but also Use-oriented Service model.

The first section of this capter is scenario development. Several scenarios regarding Product-service System which relates with furniture industry are developed. There are seven scenario developed to be evaluated in this section where two of the scenarios are considering the existence of service provider.

Scenario development for furniture industry in general have several common scenarios with simulation and experiment on observed object. However, scenario development for furniture industry, in general, is added with Use-oriented Service model which not been developed in scenario development of observed object.

Developed scenarios in this subchapter will be simulated to obtain performance measures that have been developed in previous chapter. Hence, the scenarios are compatible to be compared with existing system or another scenario.

In experiment, scenarios that has been developed are simulated in order to obtain each performance measures that has been defined in performance measure development. After obtaining peformance measure for each scenario, the results for each scenario is compared each other in order to formulate the best scenario that will be suggested to be implemented in furniture industry.

There are three evaluation conducted regarding evaluation of extension for observed object. First evaluation is conducted where UoS is not included. Second evaluation is conducted where UoS is included. Third evaluation is conducted where service provider exist. First evaluation is referred for product and PoS order. Second evaluation is referred for product, PoS, and UoS order. Third evaluation is referred for service provider who operates UoS order.

In this research, selecting the best scenario will be based on TBL. Performance measures for each TBL have been defined. Since there are several performance measures developed that will be used on the evaluation, each TBL and each performance measure required weight in order to obtain overall performance which considers level of importance for each TBL and each performance measure.

In this research, weight for each aspect of TBL is stated to be equal. It is based on (Zhang et al. 2012; Afiatna 2016) which using equal weight for each aspect of TBL in evaluating sustainability of a product and business model. Hence weight for both economy and environment aspect will be the same which is 0.5.

In order to predict unctontrollable factors that may occur on its implementation, sensitivity analysis is required to be conducted. Sensitivity analysis will be conducted under three conditions which are price markup movement, PoS willingness movement, and repair willingness movement.

Percentage of markup, percentage of PoS willingness, and percentage of repair willingness will be changed for several times in order to determine how sensitive that factors will change the decision that has been made.

Since simulation is designed to solve operational level decision, this section will analyze operational performance for selected scenario of both manufacturer and service provider evaluation

CHAPTER 7
CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Based on research that has been conducted, it can be concluded that :

1. There are two evaluation conducted in this research. First evaluation is conducted to measure performance of observed object if implementing Product-service System (PSS). In first evaluation, there are three scenarios developed to be evaluated which are product only, PoS only, and combination of product and PoS. Second evaluation is conducted to measure performance of extension of observed object if implementing PSS. There are seven scenarios developed to be evaluated in second evaluation, where two of them considers involvement of service provider who operates Use-oriented Service model.
2. In evaluation of observed object, the best scenario in terms of economy aspect is scenario 3 (Product and PoS) which generates Rp4,613,297,911 profit and 23 lost sales order. The best scenario in terms of environment is scenario 2 (PoS only) which generates 0 trashed furniture and 46.44 metric ton CO2 emission. Based on the result of best scenario selection, the best scenario for observed object by considering economy and environment aspect is scenario 2 with 0.895 overall performance.
3. In evaluation for extension of observed object without considering UoS, the best scenario in terms of economy aspect is scenario 3 (product and PoS) which generates Rp2,283,443,969 profit and 34 lost sales order. The best scenario in terms of environment aspect is scenario 2 (PoS only) which generates 18.52 metric ton CO2 emission, and 0 trashed furniture. Based on the result of best scenario selection, the best scenario for extension of observed object without considering UoS by considering economy and environment aspect is scenario 2 with 0.804 overall performance.

4. In evaluation for extension of observed object with considering UoS, the best scenario in terms of economy aspect is scenario 6 (product, PoS, and UoS by service provider without collaboration) which generates Rp2,091,125,518 profit and 41 lost sales order. The best scenario in terms of environment aspect is scenario 6 (product, PoS, and UoS by service provider without collaboration) which generates 24.15 metric ton CO2 emission, and 128 trashed furniture. Based on the result of best scenario selection, the best scenario for extension of observed object with considering UoS by considering economy and environment aspect is scenario 6 with 0.770 overall performance.
5. On extension of observed object evaluation, evaluation for service provider is also conducted. The evaluation shows establishing service provider to run UoS model is not economically feasible yet, it is proven by negative value of profit generated for both scenario involving service provider. For comparison, scenario 7 (collaboration of service provider and manufacturer) has better overall performance in both economy and environment aspect compared to scenario 7 (service provider owned the furniture for renting).

7.2 Recommendation

Recommendations that are given for future researches are as follows :

1. It requires cost analysis in determining price for Product-oriented Service and Use-oriented service.
2. In UoS, optimum inventory level and reorder point of the furniture has to be calculated and evaluated to optimize performance of UoS.
3. Evaluation has to consider the existence of another party in furniture industry like third-party repair.
4. Evaluation has to consider all aspects of TBL as parameter of evaluation.

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APPENDIX A

1. Questionnaire Form of Customer

Kuesioner Persepsi & Respon Konsumen Terhadap *Product-Service System* (PSS)
Pada Industri *Furniture*

Kuesioner ini ditujukan untuk mengetahui persepsi dan respon konsumen terhadap penerapan model bisnis *Product-Service System* (PSS) pada industri *furniture*. PSS merupakan model bisnis yang mengintegrasikan produk dengan jasa untuk memenuhi kebutuhan dan memberikan kepuasan kepada konsumen. Dengan menggunakan PSS, kebutuhan konsumen yang beragam dapat terfasilitasi dengan baik oleh perusahaan. Peneliti mengharapkan kesediaan Bapak/Ibu atau Saudara/i untuk mengisi kuesioner ini sehingga dapat dijadikan sumber informasi bagi penelitian ini.

Bagian 1 : Identitas Responden

1. Nama : .....
2. Usia : .....
3. Jenis Kelamin : Laki-laki / Perempuan
4. Pendidikan Terakhir : .....
5. Profesi : .....

Bagian 2 : Respon terhadap kondisi eksisting industri *furniture*

1. Apakah anda pernah membeli *furniture*?
   a. Ya b. Tidak

2. Untuk keperluan apa anda membeli *furniture*?
   a. Pribadi/Rumah Tangga b. Usaha/Bisnis

3. Produk *furniture* apa saja yang pernah anda beli? (boleh memilih lebih dari satu)
   a. Bed Set b. Almari/Wardrobe c. Meja Kerja d. Meja Rias
   e. Meja TV f. Rak/Laci g. *Kitchen Set* h. *Nakas/Cabinet*
   i. Sofa j. Coffee & Side Table k. Partisi Ruangan
   l. Meja Makan m. Lainnya : .....

4. Apakah *furniture* yang anda beli pernah mengalami kerusakan?
   a. Ya b. Tidak

5. Kerusakan apa yang pernah anda alami setelah membeli *furniture*?
   a. engsel/rel rusak b. Laminasi terkelupas c. Kayu berlubang/rapuh d. Pegas Hidrolik Rusak e. Finishing Sobek/Terkelupas f. Aksesoris Rusak
   g. Lainnya : .....

6. Berapa lama selang waktu terjadinya kerusakan tersebut sejak anda membeli *furniture*? (pilih dan isi lainnya jika anda mengetahui waktu pastinya)
   a. < 1 tahun b. 1 – <2 tahun c. 2 – <3 tahun d. 3 – <4 tahun e. 4 – <5 tahun
   f. > 5 tahun g. Lainnya : .....

7. Jika furniture anda mengalami kerusakan, apakah anda lebih memilih untuk memperbaikinya atau membeli *furniture* yang baru?
   a. Memperbaikinya b. Membeli Baru

Bagian 3 : Persepsi terhadap konsep PSS

1. Jika anda membutuhkan *furniture*, manakah yang akan anda pilih dari tiga penawaran berikut ini:
   a. Membeli produk *furniture* (*loose furniture*), yaitu membeli produk *furniture* secara langsung tanpa disertai layanan tambahan
   b. Membeli produk *furniture* dengan biaya lebih disertai layanan tambahan seperti servis/perbaikan, penambahan aksesoris, penggantian warna/material, konsultasi, dsb
   c. Menyewa *furniture* pada periode waktu tertentu disertai layanan tambahan berupa jasa perbaikan atau mendapatkan *furniture* pengganti jika terjadi kerusakan selama periode sewa

Bagian 4 : Persepsi terhadap konsep *Product-oriented Service* (PoS)

Product-oriented Service (PoS) merupakan salah satu bagian dari konsep PSS. Pada PoS perusahaan tidak hanya menjual produk saja, tetapi juga disertai berbagai layanan tambahan seperti servis/perbaikan, penambahan aksesoris, penggantian warna/material, konsultasi, dsb. Dengan tersedianya berbagai layanan tambahan tersebut, konsumen mendapatkan jaminan bahwa kebutuhan dan keinginan konsumen selama masa penggunaan produk dapat terfasilitasi oleh perusahaan.

1. Layanan apa saja yang anda inginkan untuk pembelian furniture yang disertai dengan layanan tambahan?
   a. Perbaikan b. Penambahan aksesoris c. Penggantian warna/material
   d. konsultasi e. Lainnya : .....

2. Apakah anda bersedia memberikan biaya lebih untuk pembelian *furniture* disertai layanan tambahan seperti servis/perbaikan, penambahan aksesoris, penggantian warna/material, konsultasi, dsb?
   a. Ya b. Tidak

3. Berapa tambahan biaya yang anda inginkan untuk pembelian *furniture* disertai layanan tambahan jika layanan tersebut berlaku selama 10 tahun setelah pembelian?
   a. 2% - <10% dari harga beli
   b. 10% - 15% dari harga beli
   c. 15% - 20% dari harga beli
   d. 20% - 25% dari harga beli
   e. 25% - 30% dari harga beli
   f. Lainnya : ..... % dari harga beli

Bagian 5 : Persepsi terhadap konsep *Use-oriented Service* (UoS)

Pada Use-oriented Service (UoS) perusahaan menjual fungsi/kegunaan dari produk, sehingga kepemilikan produk masih berada di tangan perusahaan. Salah satu bentuk dari konsep UoS adalah penyewaan produk, dimana konsumen dapat menyewa produk yang dimiliki oleh perusahaan pada periode waktu tertentu dengan tarif sewa yang telah disepakati bersama.

Saat ini trend sewa furniture masih terus berkembang di beberapa kota besar di Indonesia. Beberapa perusahaan yang berorientasi untuk menyewakan produk mulai bermunculan dengan target perseorangan khususnya ekspatriat, penghuni apartemen, perusahaan multinasional, dsb. Dengan semakin besarnya isu lingkungan dan perubahan kebutuhan dan gaya hidup masyarakat yang menginginkan kemudahan dan kenyamanan, memiliki furniture bukan lagi menjadi suatu keharusan. Sehingga di masa mendatang, menyewa furniture akan menjadi trend yang diminati oleh masyarakat.

Dengan menyewa produk dapat mempermudah pelanggan apabila terjadi kerusakan, karena produk akan diperbaiki atau diganti langsung oleh perusahaan. Selain itu, penyewaan produk dapat memfasilitasi pelanggan yang hanya membutuhkan produk pada periode waktu tertentu atau pelanggan yang ingin mengganti produk pada waktu atau kondisi tertentu.

1. Dengan semakin berkembangnya trend persewaan furniture, apakah anda berminat untuk melakukan penyewaan furniture di masa mendatang?
   a. Ya b. Tidak

2. Jenis *furniture* apa saja yang ingin anda sewa? (boleh memilih lebih dari satu)
   a. Bed Set b. Almari/Wardrobe c. Meja Kerja d. Meja Rias e. Meja TV
   f. Rak/Laci g. *Kitchen Set* h. *Nakas/Cabinet/Cradenza* i. Sofa
   j. Coffee & Side Table k. Partisi/Devider Ruangan
   l. Meja Makan
   m. Lainnya : .....

3. Berapa lama waktu yang anda perlukan untuk menyewa *furniture*? (pilih dan isi lainnya jika anda bisa menentukan waktu pastinya)
   a. < 1 tahun b. 1 – 2 tahun c. 2 – 3 tahun d. 3 – 4 tahun e. 4 – 5 tahun
   f. > 5 tahun g. Lainnya : .....

Terima kasih atas kesediaan Bapak/Ibu atau Saudara/i yang telah mengisi kuesioner ini sehingga dapat dijadikan sebagai sumber informasi bagi penelitian ini. Semoga dengan terselesaikannya penelitian ini dapat memberikan manfaat bagi industri furniture, konsumen industri furniture, maupun masyarakat secara umum.

Hormat saya,
Deni Yudhistira Rizaldi
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082111273234

2. Questionnaire Form of Service Provider

Kuesioner Respon Perusahaan Terhadap Penerapan Model Bisnis *Use-oriented Service* (UoS)

Kuesioner ini ditujukan untuk mengetahui respon perusahaan terhadap penerapan model bisnis *Product-Service System* (PSS) pada industri furniture. PSS merupakan model bisnis yang mengintegrasikan produk dengan jasa untuk memenuhi kebutuhan dan memberikan kepuasan kepada konsumen. *Use-oriented service* (UoS) merupakan salah satu bagian dari konsep PSS. Pada UoS perusahaan hanya menjual fungsi/kegunaan dari produk, sehingga kepemilikan produk masih berada di tangan perusahaan. Salah satu bentuk dari konsep UoS adalah penyewaan produk, dimana konsumen dapat menyewa produk yang dimiliki oleh perusahaan pada kurun waktu tertentu dengan tarif sewa yang telah disepakati bersama.

1. Produk apa saja yang disewakan kepada pelanggan?
   .....
   .....
   .....

2. Apakah kepemilikan produk yang disewakan berada di tangan perusahaan atau pihak lain?
   .....
   .....

3. Jika milik pihak lain, bagaimana skema bagi hasil yang dilakukan oleh perusahaan dengan pihak lain tersebut?
   .....
   .....

4. Berapa tarif sewa yang dikenakan kepada pelanggan (dalam bulan atau tahun)?
   .....
   .....

5. Jika produk yang disewakan rusak dalam periode sewa, apakah pelanggan mendapatkan furniture pengganti dari perusahaan?
   .....
   .....

6. *Treatment*/perbaikan apa saja yang dilakukan terhadap produk ketika periode sewa telah berakhir?
   .....
   .....

7. Berapa lama (dalam jam atau hari) treatment/perbaikan tersebut berlangsung?
   .....
   .....

8. Berapa biaya yang diperlukan untuk melakukan treatment/perbaikan tersebut?
   .....
   .....

9. Apakah periode sewa telah ditentukan oleh perusahaan atau berdasarkan pada kesepakatan dengan pelanggan?
   .....
   .....

10. Berapa stock furniture minimal yang dibutuhkan perusahaan untuk menyewakan produk kepada pelanggan?
    .....
    .....

11. Kapan perusahaan memutuskan untuk memesan/membeli kembali produk untuk disewakan?
    .....
    .....

3. Documentation of Observation

Educity Apartment, 1 June 2018

Purimas, 2 June 2018

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BIOGRAPHY

Deni Yudhistira Rizaldi was born in Jakarta on 31 July 1996. Author is the second son of Efrizal and Asniwati. Formal education that has been passed by the author are SDI Nurul Iman Jakarta Timur, SMP Negeri 109 Jakarta, and SMA Negeri 61 Jakarta. After that, author went to Department of Industrial Engineering Institut Teknologi Sepuluh Nopember for his bachelor degree. During his college life, author joined and participated in several organizations, events, competitions. The author joined Himpunan Mahasiswa Teknik Industri ITS as staff of education and student prosperity department from 2015-2016, and head of student prosperity department on 2016-2017.

On June 2016, the author got a chance to join manufacturing system laboratory as assistant laboratory. During his duty as assistant laboratory, the author is responsible to manage several courses such as maintenance and reliability engineering, quality control engineering, manufacturing system, manufacturing process, industrial ecology, and engineering drawing.

The author has participated in two competitions during his college life. On 2017, the author participated in Industrial and Systems Engineering Competition held by Department of Industrial Engineering Universitas Indonesia as finalist. On 2018, the author participated in Community and Technological Camp Ideas held by ITS International office for 3 minute presentation competition.

In order to implement his industrial engineering competence, the author conduct his practical work in PT Pelabuhan Indonesia III Branch of Tanjung Perak at engineering division focusing on maintenance of port equipment. The author can be contacted through email at denirizaldi@gmail.com