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Risk Assessment on Failure Factors of e-waste Management Process Using FMEA Method

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***Abstract*— Utilization of electronic products expansion dramatically in recent decades throughout the globe. Faster technological evolution is one of the causes of the high use of electronic products and makes the product obsolete rapidly. Therefore, this encourages the potential for various risks and becomes one of the problems in the sustainability of environmental management. Moreover, risk factors study in the process of managing e-waste has not been done. Therefore, this study will analyze the risk of e-waste management factors using the Failure Mode Effect Analysis (FMEA) approach. Several important information regarding the risk factors of the e-waste management process were collected using literature studies, interview methods, and fishbone diagrams. The risk factors were arranged in the form of questionnaires distributed to five respondents from various fields such as academics, the ministry of environment, the sanitation department, non-governmental organizations. The respondents were asked to provide a risk assessment based on expertise and professionalism. The result shows that several highest RPN values such as manual technology (729), number of technologies (729), legal compliance (729), and recycling costs (729). At the same time, other factors are still in the medium and low category. Thus, risk evaluation in the e-waste management process is focused on the highest risk category. Furthermore, this research can be an approach to evaluating risk management from electronic waste in DKI Jakarta-Indonesia and other developing countries. Further studies to improve the results of this research need to be carried out that will be useful for further action in the future.**

***Keywords*— e-waste; fishbone; FMEA; Risk; RPN.**

I. INTRODUCTION

The utilization of electronic products growth dramatically in recent decades throughout the world. Faster technological evolution is one of the causes of the high use of electronic products and makes the product obsolete quickly [1]. Therefore, this encourages the potential for various risks and becomes one of the problems in the sustainability of environmental management. The risks that arise in the management of e-waste are more common in the recycling process.

The recycling process of electronic waste is mostly carried out in the informal sector, which has the potential to cause environmental damage and decrease the quality of public health [2] [3]. Generally, the potential risks that arise during the recycling process of electronic waste are carried out by very simple methods in developing countries[4]. The process of recycled recycling waste has not used technology such as physical demolition using simple equipment such as hammers, screwdrivers, and chisels [5] the release of components from circuit boards by method heating; release of metals by using acid solutions to extract precious metals of gold or other precious metals, break down and recycle plastic, burning wires to take copper [6].

The recycling process of electronic waste can produce various chemical ingredients. The study conducted by Widmer et al. shows that there are around 1000 different substances in electronic waste, where they have a rich natural and can cause substantial problems in humans and the environment [2]. The electronic waste consists of a heterogeneous mixture of metals, plastics, glass, and ceramics, which contain various toxic compounds, including heavy metals and brominated flame retardants (BFRs) in the environment, mainly through industrial activities, manufacturing, waste disposal, goods spills, and accidental disposal. This has the potential to contaminate air, water, soil, sediments, plants, and wildlife [7].

The impact of exposure to a mixture of complex chemical compounds from the recycling activities of electronic waste is unknown. However, many researchers have studied the negative effects of individual chemical compounds to determine their toxic effects [8], [9]. There are many exposure pathways from PCBs around recycling sites such as dust and soil absorption, inhalation, skin exposure [10]. Moreover, Singh also explained that there are risks to human health arising from several hazardous pollutant compounds that are the result of recycling from electronic waste such as Hg, Cr, and Pb [7]. Apart from the empirical studies presented in the description above that focus on the effects of selected health effects with exposure to certain pollutants, it is almost certain that there are potential sources of pollution caused by electronic waste recycling activities that are not environmentally friendly [11], [12].

Generally, the risk analysis of e-waste management is mostly done by applying the Ecological risk assessment method [13], biological sampling [14], geostatistical methods and, quality sediment [15]. However, research on risk factors in the process of managing e-waste has not been done. Therefore, this study will analyze the risk of PCBs management factors using the Failure Mode Effect Analysis (FMEA) method. Failure mode and effect analysis (FMEA) is dynamic analysis techniques to identify the potential risk of failure of an operating system [16], [17]. The FMEA method applies inferential statistics and mathematics in determining the potential risk of process failure. Risk Priority Number (RPN) is the basis for estimating probability assessments on the FMEA method [18], [19]. In this study, the identification of potential risks is based on the process of material flow that occurs in electronic waste management. Several risk factors will be analyzed, such as technology, social, finance, recycling methods, and regulation. Risk assessment is based on the value of severity, occurrence, and detection to produce a Risk Priority Number (RPN) value. Furthermore, these values are categorized and plotted to determine strategies to reduce the potential risks that arise in PCB management from e-waste recycling.

II. Materials and Method

The research methodology is the steps that will be taken in research to achieve the desired goals. This intervention study was conducted in DKI Jakarta. Some important information regarding risk factors from the electronic waste management process was collected using literature studies, interviews with experts from various such as environmental departments, academics, and NGOs. Furthermore, these risk factors were arranged in the form of questionnaires distributed to five respondents from various fields such as academics, the ministry of environment, the sanitation department, non-governmental organizations. The respondents were asked to provide a risk assessment based on expertise and professionalism. Furthermore, the stages of risk analysis from the electronic waste management process can be seen in Figure 1.

- Determine the factors of the management system to be analyzed. The process to be analyzed is the management of e-waste in DKI Jakarta.
- Identify types of failure (failure mode). At this stage, the identification of any deviations from the management process is caused by factors of change in the system that affect the management process.

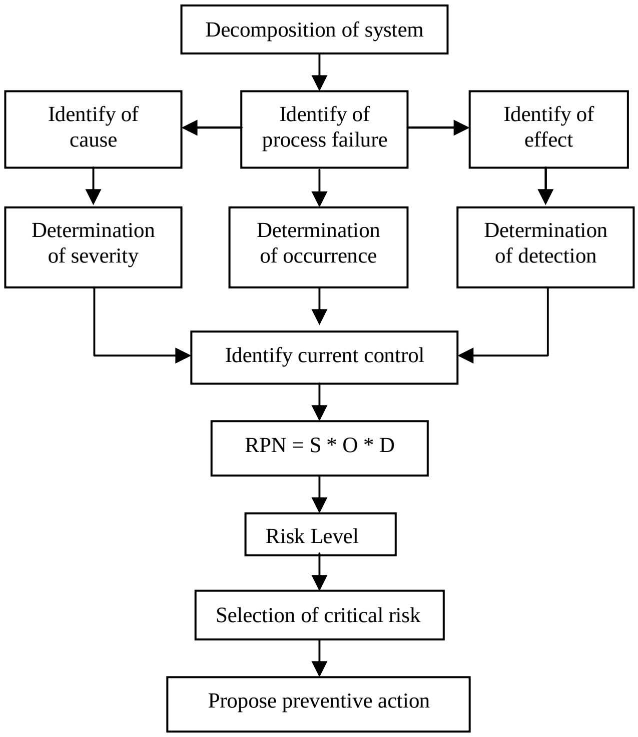

Fig. 1 The steps of risk analysis of the e-waste management process

- Identify the consequences of failure. Identify the consequences of failure mode during the management process and government regulations.
- Identify the causes of failures that occur in the ongoing process. Identify what factors can make the management process fail.
- Determination of Severity Rating (S).

TABLE I
SEVERITY RATING

Score	Effect	Severity
10	Dangerous	Malicious failure and occurs without warning. This delayed the operation of the system and did not comply with government regulations
9	Serious	Failure involves dangerous results and non-compliance with government regulations or standards
8	Extreme	The process cannot operate with the loss of primary function. The system cannot operate
7	Major	Greatly affected the performance yet functioning. The system may not operate.
6	Significant	Process performance decreases. Comfort or confidence functions may not operate.
5	Moderate	Moderate effects on process appearance. The process requires improvement
4	Poorly	Minor effects on the appearance of the process. The process does not need improvement
3	Slightly	Small effect on the appearance of the process and system
2	Very little	Very little effect on the appearance of a process and system
1	No effect	No effect

- Determination of Occurrence Rating (O).

TABLE II
OCCURRENCE RATING

Score	Probability Occurrence	Probability Failure	Score	Probability Occurrence	Probability Failure
10	Very high: failure is almost inevitable	1 from 2	5	Moderate	1 from 400
9	Very high	1 from 3	4	Relatively low	1 from 2000
8	Repeated failure	1 from 8	3	Low	1 from 15000
7	High	1 from 20	2	Slight	1 from 150000
6	Rather high	1 from 80	1	Almost impossible	1 from 1500000

- Determination of Detection (D).

TABLE III
DETECTION RATING

Score	**Detection**	**The possibility of detection by the process control**
10	Absolute uncertainty	The control process will not and/or cannot detect potential causes/mechanisms and subsequent failure modes
9	Very little	Very far the possibility of process control will detect potential causes/mechanisms and subsequent failure modes.
8	Little	The possibility of process control will be able to detect potential causes/mechanisms and subsequent failure modes.
7	Very low	The possibility of very low process control will detect potential causes/mechanisms and subsequent failure modes.
6	Low	The low possibility of process control will detect potential causes/mechanisms and subsequent failure modes
5	Moderate	The possibility of moderate process control will detect potential causes/mechanisms and subsequent failure modes.
4	Rather high	A high enough chance of process control will detect potential causes/mechanisms and the next failure mode.
3	High	Most likely, Control Design will detect potential causes/mechanisms and subsequent failure modes.
2	Very high	The very high probability of process control will detect potential causes/mechanisms and subsequent failure modes.
1	Almost certain	Process control is almost certain to detect potential causes/mechanisms and subsequent failure modes.

- Identify the current control that has been done to prevent failure mode. Identify the activities that have been carried out by the provincial government to address the failure of the process.
- Determine the value of the Risk Priority Number (RPN). The RPN confirms the priority level of failure. The value of the RPN depends on the value of the severity rating, occurrence rating, and detection rating. The formula used to calculate RPN is:

$$RPN = S \times O \times D \quad (1)$$

- Determine the risk level. Based on the results of the calculation of the RPN, the risk level can be determined.
- Determine critical risk. Determination of critical risk by referring to the highest RPN value.
- Proposed preventive action. Determination of preventive actions that can be proposed to reduce potential risks in the future.

III. RESULTS AND DISCUSSION

A. *Risk Assessment of Current e-Waste Management*

Risk identification or system decomposition is an integral aspect of risk analysis. Risk consists of three conceptual elements consisting of objects that are considered to present risks, suspected losses, and special links that represent causal forms between objects and hazards. In this study, the object is the potential risk of electronic waste management. This is based on many studies that show that electronic waste results in a decrease in the quality of the environment and human health.

E-waste can be seen as an item that is discarded or disposed of because it has dangerous properties and has no value. All e-waste can be recycled to reduce pollution such as air, water, soil, radioactive pollution, and heat, thus making the environment healthier and conducive to living things. Moreover, recycling can also generate economic value for individuals, organizations, and governments. Thus can improve the standards and welfare of people living in certain environments. Recycling in the right way and following the standards used by everyone can achieve sustainable development in this modern world. The process of managing electronic waste, in addition to providing value for economic benefits, can also potentially pose a risk of environmental damage and a decrease in human health. To understand waste management can refer to the flow of e-waste described in Figure 2.

Based on Figure 2, it can explain the flow of e-waste in DKI Jakarta, starting from households, pickers, electronic product repair services, collectors and, manufacturing industries. Thus, it can be concluded that the management of e-waste is very dependent on the informal sector—the role of the informal sector in management, such as collecting, dismantling, and recycling. The activities of the informal sector in managing e-waste have the potential to pose a risk to the environment and human health. Furthermore, the risk of failure of the e-waste management process is also caused by various factors such as technology, social, financial, recycling, and regulation.

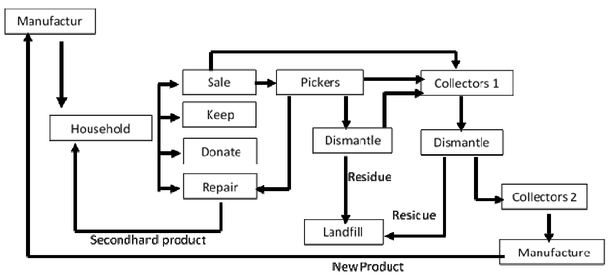

Fig. 2 The steps of risk analysis of the e-waste management process

There are several risk factors found in the literature. Research by Pang et al. states two risk factors in general, natural and human risk factors [20]. An inherent aspect and can be controlled but cannot be eliminated, and the latter can be pre-controlled; however, one or several human factors can be a factor of initiation for this study. Sumner presents a list of risk factors, for example, institutions, skills, management strategies, system design, training, technology planning, and social commitment [21]. Furthermore, Chua Alton presents a list of risk factors consisting of four main categories, namely: related to humans as executors, process activities, technical and new features for work [22]. Moreover, the authors acknowledge that human risk factors consist of four categories; inexperienced users, lack of stakeholder involvement, overly ambitious top managers, and users who are not properly trained to use the system.

To determine the potential risk of failure in the management of e-waste, then made fishbone diagrams or fishbone diagrams to define the cause and effects of problems. Technological factors, the use of technology by humans, is intended to increase productivity and obtain maximum profits. Furthermore, technology is expected to be able to suppress the extent of damage and the possibility of potential hazards. Increased environmental problems caused by the use of technology are more dominant than the increase in population. Environmentally friendly technology must be adapted to the local socio-economic, cultural, and environmental conditions [2] [23] [24].

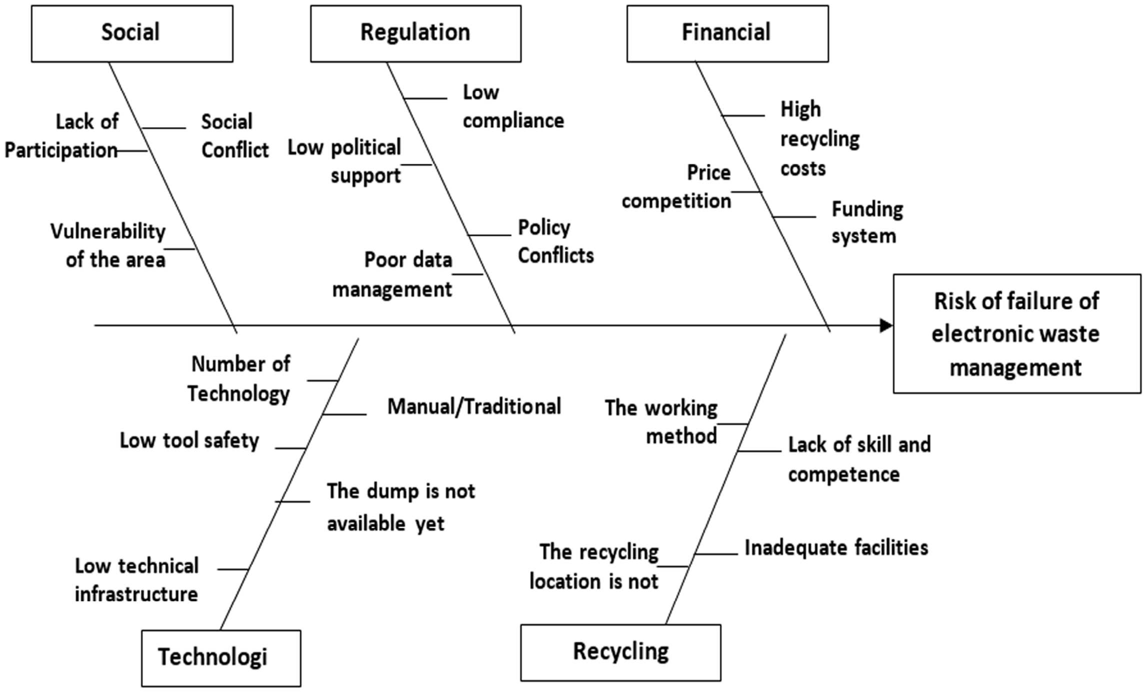

Fig. 3 Fishbone risk diagram failure e-waste management process

One effort that can be done in terms of increasing environmentally friendly technological innovation is the transfer of technology from developed countries to developing countries. Technology transfer is a terminology that harmonizes the technology transfer activities from an advanced industrial nation to a developing country. Therefore, that is usually interpreted as an event to help developing countries to build industries to improve the quality of life. This includes changes to the manual/traditional work system by using better equipment, adequate technology, safety for technology users, and infrastructure, and technical support [2], [24], [25].

Various factors that contribute to the potential for failure in implementing regulations related to waste management include legal compliance, lack of political support, policy conflicts, and poor data management. These factors play an important role in supporting the implementation of changes to regulations e-waste management [2], [24]. The study conducted by Makondo et al. reviewed compliance with environmental management by industries extracting mining products in Zambia [26]. Furthermore, the study found a failure of 8 out of 10 mining companies to submit periodic reports following licensing regulations. Besides, regulations are not well understood and effectively implemented. Research conducted by Uchendu also found legal non-compliance with the management of solid waste in Nigeria [27]. Furthermore, the non-compliance was caused by the law enforcement of environmental regulations.

Social factors, sustainable development is the integration of environmental, socio-economic, and social equilibrium. In the context of waste management, social sustainability can be defined as providing appropriate services to meet public health. Community perceptions and participation in waste management have a high significance with waste management systems [24]. Birhanu and Berisa, an emphasis that important factors for failure of solid waste management in developing countries are due to a lack of perceptions and public participation [28]. The level of perceptions and roles can lead to attitudinal and behavioral gaps that can lead to non-functioning waste management systems [29], [30].

The recycling factor is one of the waste management strategies, which consists of the activities of sorting, collecting, processing, distributing, and making used products/materials. The waste treatment efforts aim to utilize material that is still useful for reuse and indirectly can extend the life of the landfill. Some of the benefits of recycling activities, namely: saving energy use, reducing acid rain, increasing earth temperature, and air pollution due to the process of burning waste, can save natural resources, reduce water, air, and soil pollution. Recycling activities in waste management have the potential to fail because of several factors such as low skills and competencies of workers [31], inadequate work facilities, poor methods of work, and recycling locations that are not centralized [24], [32].

Financial factors, in general, waste can provide financial benefits for several stakeholders who carry out recycling activities. However, the potential risk of failure of the waste management process can also occur due to a lack of financial support [24], [32], [33]. Several factors that can drive the failure of an effective waste management process include the high cost of recycling waste management, the existence of price competition, and the funding system.

Based on the description of each of these factors, further analysis, and risk assessment. Making the right decisions in risk management is not an easy task. Therefore, the risks identified must be explained in a way that is understandable and then analyzed systematically. As a result, each risk, when identified, must be analyzed in terms of potential possibilities that can occur. The risk is always analyzed in terms of probability and serious impact. Furthermore, these impacts can be assessed by giving the following rating low, medium, and high. Based on the results of the questionnaire given to several experts who are considered experts and understand the management of electronic waste, the results obtained in Figure 4 below. Risk evaluation is one of the stages in decision making related to the level of risk and priority of risk. Risk treatment is carried out after an assessment involving the evaluation and selection of options on how to manage risk. The risk is acceptable if it is not followed up. Accepting a risk does not indicate that the risk is not significant. This risk can be accepted with several considerations, such as a very low level of risk so that no special treatment is needed in the available resources.

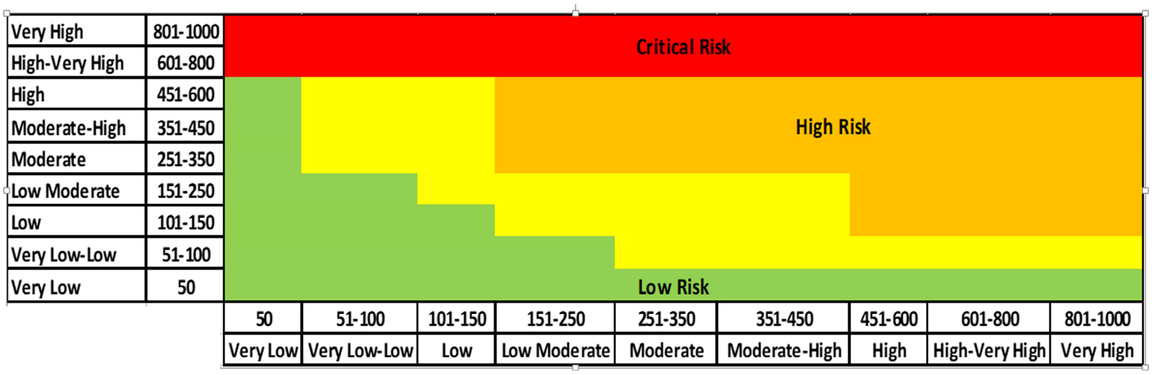

Fig. 4 Risk matrix of FMEA

In the context of risk, aversion can be done by not continuing an activity that contains unacceptable risks, or in other words choosing a more acceptable alternative activity that meets the goals and objectives of the organization. Moreover, it can be done by choosing alternative methods and processes that are not too risky in activity activities. Transfer risk or transmit risk to the other party. This risk transfer method is often used in purchasing insurance or compensation. The circumstances and transfer costs will depend on the level of guarantee that management can provide to other parties in the event of a claim. The other party will need information related to the type of risk, the strength of the existing system, and the history of the risk itself.

TABLE IV
RISK LEVELS OF E-WASTE MANAGEMENT

No	Factors	Sub-factors	RPN	Risk level	Recommendation action
1	Technology	Traditional/manual	729	High-Very High	Prevention
2		Safety on equipment	125	Low	Accept
3		Infrastructure	80	Very Low	Accept
4		Number of technology	729	High-Very High	Prevention
5		Recycling location	245	Low-Moderate	Accept
6	Regulation	Obedience law	*729*	High-Very High	Prevention
7		Politic supports	245	Low-Moderate	Accept
8		Conflict of policy	216	Low-Moderate	Accept
9		Data management	441	Moderate-High	Mitigation
10	Social	Community participation	249	Low-Moderate	Mitigation
11		Social conflict	324	Moderate	Mitigation
12		Regional vulnerability	125	Low	Accept
13	Recycling	Skill and competency	100	Very Low-Low	Accept
14		Recycling facilities	567	High	Mitigation
15		Work method	567	High	Mitigation
16		Centralization of the recycling site	486	High	Mitigation
17	Financial	Recycling cost	729	High-Very High	Prevention
18		Price competitiveness	441	Moderate-High	Mitigation
19		Financial system	441	Moderate-High	Mitigation

Controlling risk is an alternative that is often used to reduce the possibility of the occurrence of risks and the impact of risks that will occur in the future. Generally, there will be a change between the level of risk and the reduction in risk to an acceptable level. The most effective risk control method is to redesign the system and process so that the possibility of potential negative risks can be reduced. Several things must be done in risk control such as eliminating all potential hazards if possible, for example, the use of safer chemicals. Moreover, if the elimination of risk cannot be carried out, it is necessary to replace the material or process by giving more impact to small risks such as installing or using additional equipment. Moreover, risk reduction can also be carried out by administratively controlling and applying safer work systems such as the development of work instructions, policies, guidelines, or standard operating procedures. From the calculation on the FMEA matrix, then the risk level is categorized on each factor. The risk assessment categories are based on figure 4.

Several factors can be categorized as very high risks such as manual technology, amount of technology, legal compliance, and recycling costs. This requires preventive measures to avoid greater negative impacts in the future, furthermore, for factors whose risks are acceptable to include security and safety of equipment, technical infrastructure, recycling locations, political support, policy conflicts, regional vulnerability, skills, and competency of workers. This is because the assessment results from experts show a low-risk value. Therefore, there is no action needed. Moreover, several other risk factors that must be considered include data management, public perception, and participation, social conflict, recycling facilities, work methods, centralization of recycling locations, price competition, and funding systems. This may potentially cause negative risks in the future. Thus, it is deemed necessary to carry out mitigation activities to prevent future losses both in terms of decreasing environmental quality and the quality of human health.

The results of the risk assessment, as described above, can be interpreted that the potential failure of the electronic waste management process is very large. Thus, this may disrupt the dimensions of sustainable development concerning waste management. This research has helped in identifying various risk factors that could potentially weaken the sustainability of electronic waste management in DKI Jakarta. Several risk factors have been identified, such as technology, regulatory/legal, social, and financial recycled.

From the technology perspective, it can consist of several sub-factors such as traditional technology/manuals, security and safety tools, technical infrastructure, number of technologies, unique recycling locations. Moreover, in the context of regulation/law, it consists of legal compliance, political support, policy conflicts, and data management. Social factors consist of perceptions and community participation, social conflict, and regional vulnerability. The financial perspective consists of recycling costs, price competition, and funding systems. Ultimately, some other factors on risk assessment such as recycling skills and competence of low labor, recycling facilities, working methods, and centralized recycling location.

B. *Proposed the Sustainable E-waste Management System Strategy of Informal Sectors in DKI Jakarta*

The sustainable E-waste management system is a necessity that must be done to reduce the potential risk of damage to the environment and human health declining. It should take into account various factors such as the volume and types of electronic products, current sales of electronic products, recycling practices in the formal and informal sector, government regulation, the type of e-waste processing, social and cultural practices of the community, stakeholders responsible.

1) The Extended Producer Responsibility (EPR) approach. It can be proposed in the e-waste management system in DKI Jakarta. There are several objectives of EPR implementation, such as minimizing e-waste volume, reducing e-waste disposal, reducing harmful compounds in e-waste, reducing original material usage, minimizing pollution, and improving environmental quality. The implementation of EPR programs has been widely carried out in Asian and European countries such as Japan, Korea, Taiwan, Switzerland. The application of transportation and recycling costs is made by the people who dispose of e-waste in Japan. Furthermore, producers pay recycling costs in Korea and Taiwan. Moreover, the joint organization is formed by producers to manage e-waste, and its processing is distributed in the formal sector that has a license in Switzerland.

Furthermore, regulations EPR in developed countries have been taken seriously. However, existing regulations in Indonesia do not specifically regulate e-waste management. For example, Indonesian Government Regulation No. 81 of 2012, as a derivative of Law No. 18 of 2008, only regulates waste management from households and does not cover e-waste. In these regulations, the manufacturer shall withdraw (take back) the garbage for recycling gradually. Moreover, the regulation and management of electronic waste still refer to regulations governing hazardous and toxic waste such as Law No. 32 of 2009 concerning Environmental Protection and Management; PP No. 101 of 2014 concerning B3 Waste Management. However, all these regulations only regulate in general and do not specifically specify the definition, criteria, and flow of electronic waste management.

Formulation of an EPR program should include the formulation of system management e-waste collection, take back system by providing incentives for increasing public awareness. The public-private partnership system is like providing a collection point in supermarkets for collection, providing environmentally sound technology to the e-waste processing industry, subsidy schemes from the government, and other funding sources. The formulation of the EPR also needs to integrate the informal sector as an existing player, for example, as part of waste collection activities from the household sector. However, there is potential for the formality of the informal sector who have met the requirements and following applicable regulations.

2) The application of environmentally friendly recycling technology: it can be an e-waste management option because it will increase the material recovery value in e-waste. The use of environmentally friendly recycling technology can be done at each level of processing in the e-waste stream.

Broadly speaking, environmentally friendly recycling technology has high technical characteristics and expensive investment costs. Also, the operational process requires special skills from the operator.

3) Training in the informal sector: One recommendation that can improve the sustainable management of e-waste is training in the informal sector. This training can be initiated by the local government or the central government. Training materials for workers, such as the use of more environmentally-friendly equipment, the use of PPE during the recycling process are more efficient and effective work methods. Through the provision of training and training, it will motivate workers to work safely without having to pose potential environmental risks and still get better life from an economic perspective.

4) Dropbox: The development of the collection program through Dropbox can also be an option in managing e-waste. Dropbox is placed in various locations to collect e-waste from the community. Dropbox placement also requires officers or volunteers who can provide explanations to the community. Dropbox placement should be done in educational institutions and government institutions. Dropbox placement without any officers or volunteers cannot run effectively to encourage community participation. Furthermore, the manufacture of Dropbox can be done by producers, retailers, or parties related to e-waste management.

IV. Conclusion

The application of electronic products in the last decade in developed and developing countries has grown dramatically. This encourages potential risks in the recycling process. Therefore, risk evaluation and analysis are needed to correct or eliminate failures before process performance decreases. The method used in this risk assessment is FMEA. The calculation results show the highest RPN value is manual technology (729), total technology (729), legal compliance (729), and recycling costs (729). At the same time, other factors are still in the medium and low categories. Thus, risk evaluation (priority risk to be controlled) in the electronic waste management process is focused on the highest risk category. The results of this study can be a new approach to evaluating the risk of electronic waste management in DKI Jakarta-Indonesia and other developing countries. Further studies to improve the results of this research need to be carried out that will be useful for further action in the future.

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