

PAPER • OPEN ACCESS

## Eco-Process Innovation Performance: Production Waste Investigation through Discrete Event Simulation

To cite this article: S M Dahan and S M Yusof 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **697** 012001

View the [article online](#) for updates and enhancements.

# Eco-Process Innovation Performance: Production Waste Investigation through Discrete Event Simulation

S M Dahan<sup>1</sup> and S M Yusof<sup>2</sup>

<sup>1</sup> Faculty of Industrial Management, Universiti Malaysia Pahang, Malaysia.

<sup>2</sup> Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Malaysia.

Email: suziedahan@gmail.com

**Abstract.** Eco-process innovation has been recognised as an effective green strategy for altering manufacturing processes so as to improve a firm's environmental performance. As many recent eco-innovation studies focusing on perceptual approach of investigating the performance indicators, new study opportunity knocked the door for new knowledge disclosure of operational approach, since it has been largely ignored. This paper aims to assess production waste improvement brought by eco-process innovation implementation in a manufacturing facility. For this purpose, the discrete event simulation approach has been applied to model and simulate the waste rate of previous state and current state of an eco-innovatively improved production line, using the real operational data. Comparison between both states of production system demonstrated a reduction of 0.14% and 0.02% in waste rate at visual mechanical inspection and final test inspection points consecutively, hence confirmed that eco-process innovation practice enabled the improvement of the environmental performance of manufacturing firm. The study is a small part of a larger research work of which the authors are developing indicators for measuring eco-process innovation performance at the firm level.

## 1. Introduction

While manufacturing operations are essential for elevating the humankind quality of life, they are proven to also contribute to the harmful impacts on the environment. Thus, in the recent decade, manufacturers are proactively seeking a secret recipe for improving their operational performances without jeopardising the ecosystem's sustainability. Studies have revealed that there is a positive association of eco-process innovation (also recognised as environmentally friendly changes taking place in production processes) with firms' competitive advantage [1–5]. Cheng et al. [6] referred eco-process innovation as the introduction of new production processes or modification of existing processes so as to minimise the negative impacts of environment. It is a type of technical improvement which utilising environmental friendly technologies to avoid or reduce environmental degradation [7] and promoted internally at the level of the individual firm [8]. This paper covers eco-process innovation that is defined by [9] as eco-innovative improvement done on the production processes which resulted in the enhanced firm's performance of economic, environmental and social.

In view of eco-process innovation performance, [10–13] revealed that its implementation could lead to better wealth generation, and environmentally and socially responsible firm. Adoption of eco-process innovation practice could not only results in better environmental quality but also enhanced the economic achievement and social through the responsible use of resources and the reduced hazardous waste, pollution and emission during the production process. According to [6], the performance measure of eco-process innovation covers the assessment of production process which minimises the generation



of harmful waste and substances, recycles and reuses waste and emission and improves resources usage such as raw material, water, electricity, coil or oil.

In the context of the assessment approach of eco-process innovation performance, a comprehensive system to track and monitor its effectiveness needs to be established. Such an assessment system should consist of indicators which are measurable and quantifiable [14,15], relevant [14,16], reliable and accessible [15,16]. However, various versions of indicators introduced and employed to measure eco-process innovation, in which they are still broad in nature and vary with contexts where they have been applied [17–20]. This study addresses the production waste, an indicator to represent the environmental performance of the production process. This study aims to assess the improvement in the waste rate following the eco-innovative changes done on the production processes. For the purpose, the actual production data of a manufacturing plant was used to quantify the improvement. Changes in the waste produced by a production line of interest have been modelled and simulated using a popular simulation-based analysis, namely discrete event simulation (DES) method.

## 2. Literature Review

Firms' commitment to undertaking eco-innovation initiatives is causing additional costs to them. However, such investments are worthwhile as studies demonstrated that eco-innovation practices brought positive effects to the firms [3,21]. Eco-process innovation has been proven to cause the firm to achieve a better performance in the aspect of economic, environmental and social [10–13,22–25]. Prior study by [24] on manufacturing firms by taking the triple bottom line (TBL) into consideration, discovered a significant connection between eco-innovative changes done on processes and firms' sustainability performance, and they recommended firms to deliberate in such initiatives to obtain better performance of economic, environmental and social. Similarly, a recent review of eco-innovation concept by [12], who equalised eco-innovation with sustainable innovation, viewed eco-innovation as promoting sustainable development concept by enhancing consumers' quality of life, thus improving not only the environmental and economic aspect but also the norms and values of society. [13] added that eco-innovation adoption contributed to protecting the social well-being by using the natural resources responsibly and refraining the harmful impacts on the environment.

In the context of environmental impacts, ecological innovation introduced in the manufacturing process has been proven to minimise the harmful impacts on the environment. It was noted that productive resource usage, less pollution and waste and more efficient production processes could be achieved through the conduct of eco-process innovation [11]. Most manufacturers are investing in eco-process innovation technologies to gain waste reduction and energy efficiency [26]. The technology and process upgrades may cause more efficient manufacturing processes and logistics, and greater resource productivity, thus leading to less waste and much cost savings [27,28]. Reduction of production costs may also be possible through the practice of reusing, recycling and remanufacturing. These practices done on resources such as materials causes a reduction in the consumption of new materials, provide a greater capacity of acquiring other resources and less waste production by the process.

## 3. Methodology

A single case study method has been applied to assess the production waste using the actual operational and production data. A Malaysian electronic components manufacturer has been chosen as the case study company. The company produces a wide variety of customised and standard common mode chokes, transformers and power inductors for medical, automotive, alternative energy and industrial sectors applications.

The waste assessment was carried out on a common mode choke production line. The line is the longest and long run production line due to the continuous and large order quantity of the product model. Previously, most processes were done manually by the operators. Later, as the company adopting the continuous process improvement to enhance their performance, most critical processes were gradually upgraded and transformed. The production operation starts with the arrival of insulated wires at the

stripping and cutting process and come to an end when the finished common mode chokes are placed into the protecting packages and labelled for transfer to the warehouse department. All defective items found at the visual mechanical inspection (VMI) and final test inspection is rejected, recorded as scrap, discarded and transferred to the scrap yard. The rejected parts due to the mechanical or electrical defects are not reworked or repaired, hence considered as production waste. This study refers to production waste as the defective items found and rejected at VMI and final test inspection points, thus the rate is computed based on the rejected quantity per the inspected quantity.

Simulation models were developed using Arena Version 15 simulation software. According to Thiede et al. [29], Arena software is a recommended simulation software due to its capability to evaluate the diverse production performances and simultaneously coping with the assessment of environmental aspects such as waste and energy usage.

### 3.1. Data collection

Various types of data, gathered from numerous sources in the case study company were used so as to ensure the real world production line was accurately visualised by the Arena modules:

- i. Structural data was used to design the structure of the model such as the production line layout and process control plan.
- ii. Process parameter which include production planning and control and processing time.
- iii. Process parameter relationships such as process improvement projects details to visualise the interdependencies of the parameters.

The processes cycle time were directly measured through time study conducted on all processes. The computation of minimum sample size of observations was performed based on the following formula which suggested by [30], to make sure that the measured cycle time was representative.

$$n = \left( \frac{40\sqrt{n'\sum x^2 - (\sum x)^2}}{\sum x} \right)^2 \quad (1)$$

where,  $n$  is the sample size,  $n'$  is the number of readings taken in the preliminary measure,  $\sum$  is the sum of values and  $x$  is the value of the readings. Preliminary measure of cycle time was performed on each processes, whereby the readings then were used to compute the appropriate sample size for the actual measure of cycle time.

### 3.2. Analysis of input data

Before the observed data could be applied as input to the simulation models, they were evaluated and categorised as either deterministic (non-random data) or stochastic (random data). Deterministic data for instance the resource capacity was used directly. Stochastic data like the time between arrivals, on the other hand, was fitted to a probability distribution by performing the goodness-of-fit test in Input Analyzer (an Arena software distinct application). Three numerical measures were used, such as suggested by [31], to analyse the results of goodness-of-fit test and decide if the data fits the proposed probability distribution:

- i. Square error - good fit is described by smaller value.
- ii. Chi-Square and Kolmogorov-Smirnov (K-S) – good fit is corresponded by greater than 0.05 p-value.

### 3.3. Development of Simulation Models

Two models were constructed to visualise the production line of interest, referred as previous state to represent the production line prior to the implementation of the eco-innovative improvement, and current state to illustrate the post-eco-process innovations production line.

#### 3.3.1 Previous State Modelling.

Figure 1 shows the previous state model which consists of 20 processes.

### 3.3.2 Current State Modelling.

The structural and quantitative change was used to represent the eco-improvements in the current state model (illustrated in Figure 2). Structural change refers to the model structure change, such as the change of process order. Whereas quantitative change involves the input value change for example the change of process cycle time [32]. The eco-innovative changes conducted on the production line and the corresponding changes made on the model are summarised in Table 1.

**Table 1.** Eco-process innovation and the respective modelling change

<b>Eco-Process Innovation</b>	<b>Type of Model Change</b>	<b>Model Change</b>
Efficient Equipment Manual to auto winding jig	Quantitative	Shorter process cycle time
Process Automation: Manual to auto tinning machine	Quantitative	Shorter process cycle time
Process Integration: Curing 1 & Curing 2	Structural	Reduced process from 2 to 1
Process Integration: Cooling 1 & Cooling 2	Structural	Reduced process from 2 to 1

### 3.4. Model assumptions

The following assumptions were made when running the simulation models:

- i. Breaks period were excluded from the daily production operation of 8 hours and 50 minutes.
- ii. Process cycle time has considered the entity transfer time.

Both models were simulated in the steady-state simulation setup with 100 replications; warm up period 10,000 seconds; 1-day production operation replication length and 11.6112 hour per day (31,800 seconds plus 10,000 seconds). Such as recommended by [31], the initialisation bias of steady-state simulation needs to be eliminated by setting up the warm-up period. Preliminary runs with multiple replications of both models were performed and Output Analyzer was applied to produce the statistical plot of the saved data in order to examine the appropriate warm-up period.

### 3.5. Verification and validation of simulation models

Concerning the models' verification, processes sequence of the real production line process sequence was compared and verified by the line leader (of the case study company) to ensure that the models' structural logic was accurately representing the real production line under investigation. Apart from that, the detail modules setting was also examined through animation running and the generated SIMAN coded files.

Both models were validated by performing the goodness-of-fit tests on the stochastic cycle time. Moreover, the collected actual data was compared with the simulation results, whereby a minimal difference or error justifying the models' validity.

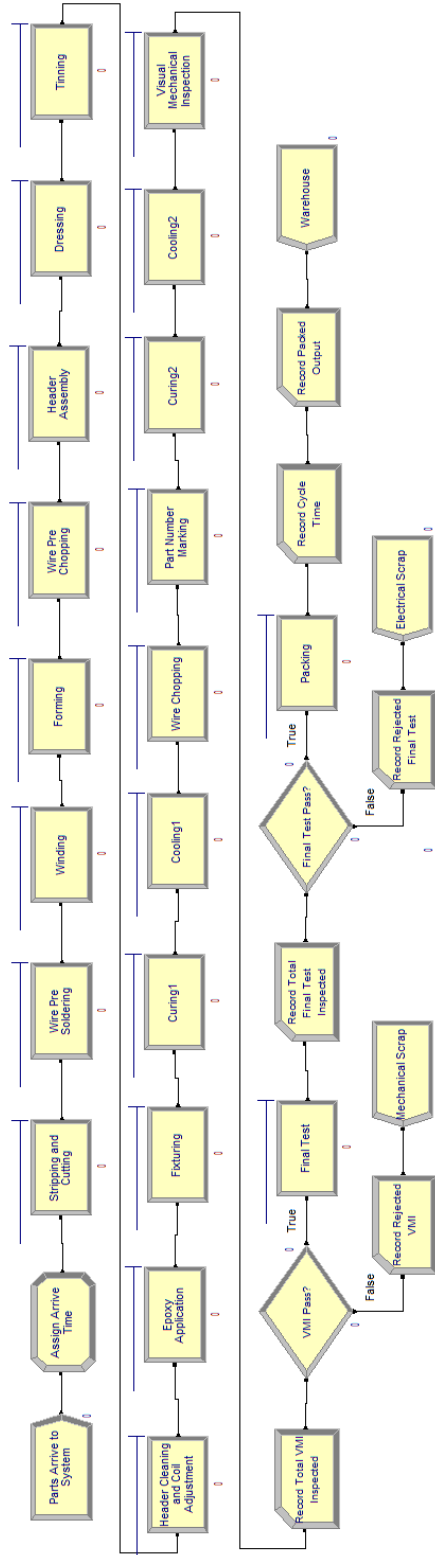


Figure 1. Simulation model of previous state production line

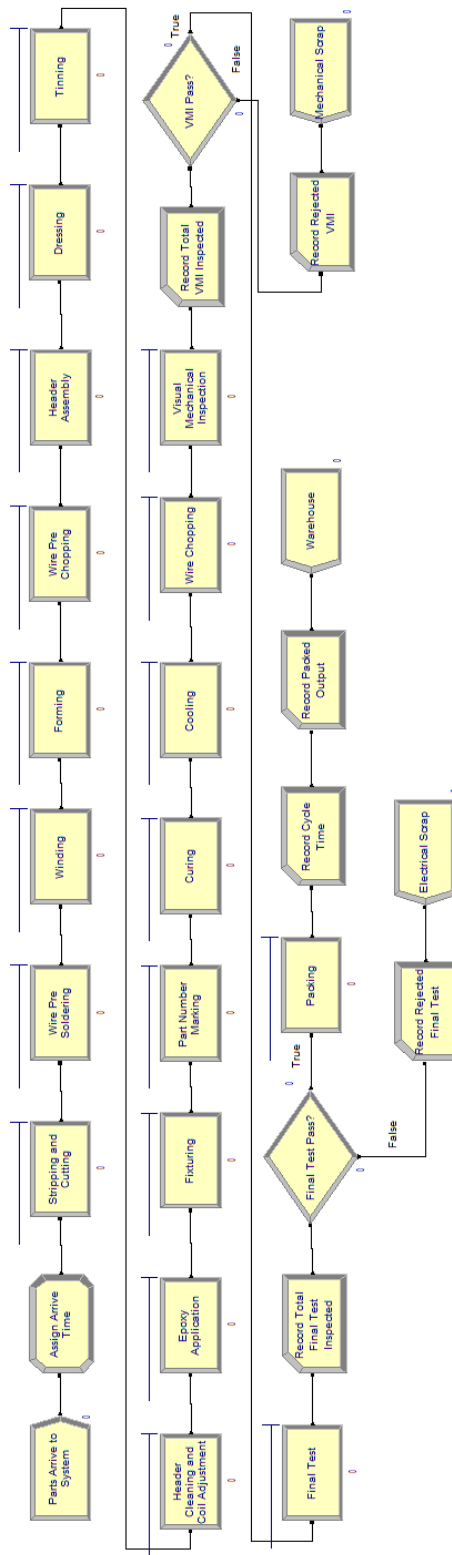


Figure 2. Simulation model of current state production line

### 3.6. The improvement results

Table 2 shows the simulation results of production waste for previous and current state models of production line.

Table 2. Simulation results of production waste

	<b>Production Waste</b>	<b>Previous State</b>	<b>Current State</b>
<b>Rejected VMI</b>	Rate	2.46%	2.32%
	Average	172.3	163.01
	Half-width	2.60	2.62
	Minimum Average	141.00	128.00
	Maximum Average	197.00	196.00
<b>Rejected Final Test</b>	Rate	0.08%	0.06%
	Average	5.29	4.23
	Half-width	0.47	0.37
	Minimum Average	1.00	1.00
	Maximum Average	12.00	9.00

It is apparent from the above table that the total rejected entities at VMI counter has reduced from 172.3 to 163.01 entities (with 7,012.09 inspected entities) during the simulation period. The result recorded the improvement of VMI rejection by 0.14% after the implementation of eco-process innovations in the production line. Besides that, at final test counter, a reduction of 0.02% has been demonstrated with the reduction of rejected entities from 5.29 (with 6,839.83 inspected entities) to 4.23 (with 6,849.10 inspected entities). Overall, this study discovered differences in the production waste rate before the eco-process innovation and after the improvement of a few production processes. These improvements suggest that the continuous eco-process innovation implementation can help to reduce the production waste rate, hence improves the environmental performance of manufacturing firm.

## 4. Conclusion

This paper concerns the assessment of eco-process innovation environmental performance, denoted by the improvement of production waste rate in particular. DES simulation results demonstrated reductions in the waste rate after the eco-process innovation than those generated by production operation prior to the eco-process improvements. The reduction of waste rate after the adoption of eco-process innovation is suggestive of better environmental performance following the continuous eco-improvement of processes. This study enriches the operational method of measuring the improvement in the production line resulted from the implementation of eco-process innovation. Moreover, this study also highlights the potential application of simulative study to assess the performance of eco-process innovation in E&E manufacturing firm. In a future investigation, it might be possible to conduct a similar study approach to measure other environmental indicators of eco-process innovation such as energy usage.

## References

- [1] Y.S. Chen, S.B. Lai and C.T. Wen, *The Influence of Green Innovation Performance on Corporate Advantage in Taiwan*, J. Bus. Ethics 67 (2006), pp. 331–339.
- [2] S.B. Karaarslan, *Eco-Innovation Competitiveness Inland shipping*, Erasmus University Rotterdam, (2015).
- [3] J. Hojnik and M. Ruzzier, *The Driving Forces of Process Eco-Innovation and Its Impact on Performance: Insights from Slovenia*, J. Clean. Prod. 133 (2016), pp. 812–825.

- [4] J. Horbach, *Impacts of Regulation on Eco-Innovation and Job Creation*, IZA World Labor (2016), pp. 1–10.
- [5] J. Hojnik, M. Ruzzier and T.S. Manolova, *Internationalization and Economic Performance : The Mediating Role of Eco-Innovation*, J. Clean. Prod. 171 (2018), pp. 1312–1323.
- [6] C.C.J. Cheng, C. Yang and C. Sheu, *The Link Between Eco-Innovation and Business Performance: A Taiwanese Industry Context*, J. Clean. Prod. 64 (2014), pp. 81–90.
- [7] T. Kong, T. Feng and C. Ye, *Advanced Manufacturing Technologies and Green Innovation: The Role of Internal Environmental Collaboration*, Sustainability 8 (2016), pp. 1056.
- [8] M. Sanni, *Drivers of Eco-Innovation in the Manufacturing Sector of Nigeria*, Technol. Forecast. Soc. Change 131 (2018), pp. 303–314.
- [9] S.M. Dahan, S.M. Yusof and M.Y. Taib, *Performance Measure of Innovation :Insights from a Literature Review*, in UTP-UMP SES 2017, 131 (2017).
- [10] S. Scarpellini, J. Aranda-Usón, M.M. Fondevila, A. Aranda-Usón and E. Llera-Sastresa, *Eco-Innovation Indicators for Sustainable Development: The Role of the Technology Institutes*, Int. J. Innov. Sustain. Dev. 10 (2016), pp. 40.
- [11] E. Calik and F. Bardudeen, *A Measurement Scale to Evaluate Sustainable Innovation Performance in Manufacturing Organizations*, Procedia CIRP 40 (2016), pp. 449–454.
- [12] A. Kowalska, *Implementing Eco-Innovations. Determinants and Effects*, Ann. Polish Assoc. Agric. Agribus. Econ. XVI (2017), pp. 153–158.
- [13] A. de Jesus, P. Antunes, R. Santos and S. Mendonça, *Eco-Innovation in the Transition to a Circular Economy: An Analytical Literature Review*, J. Clean. Prod. 172 (2018), pp. 2999–3018.
- [14] A. Davidescu, A. Paul, R.-M. Gogonea and M. Zaharia, *Evaluating Romanian Eco-Innovation Performances in European Context*, Sustainability 7 (2015), pp. 12723–12757.
- [15] M.S. Park, R. Bleischwitz, K.J. Han, E.K. Jang and J.H. Joo, *Eco-Innovation Indices as Tools for Measuring Eco-innovation*, (2017), pp. 1–29.
- [16] C.B. Joung, J. Carrell, P. Sarkar and S.C. Feng, *Categorization of Indicators for Sustainable Manufacturing*, Ecol. Indic. 24 (2013), pp. 148–157.
- [17] V. Oltra, R. Kemp and F.P. Vries, *Environmental Innovation France: Dynamics of Institutions and Markets in Europe (DIME)*, (2009).
- [18] A. Reid and M. Miedzinski, *Eco-innovation: Final Report for Sectoral Innovation Watch Project*, Technopolis, (2008), Available at: [www.technopolis-group.com](http://www.technopolis-group.com).
- [19] A. Arundel and R. Kemp, *Measuring Eco-Innovation*, ISSN 1871-9872, Maastrich, Netherlands: United Nations University, (2009).
- [20] L.F.C. Basso, A.C.S. Braga, D.F.L. Santos and H. Kimura, *Eco-Innovation in Brazil. The Creation of an Index*, Bus. Manag. Rev. 4 (2013), pp. 1–17.
- [21] J. Conding, N.F. Habidin, A.F. Mohd Zubir, S. Hashim and N.A. Seri Lanang Jaya, *The Structural Analysis of Green Innovation ( GI ) and Green Performance ( GP ) in Malaysian Automotive Industry*, Res. J. Financ. Account. 3 (2012), pp. 172–179.
- [22] B. Bossink, *Eco-Innovation and Sustainability Management*, Taylor & Francis Group, New York, (2012).
- [23] D. Gadenne, L. Mia, J. Sands, L. Winata and G. Hooi, *The Influence of Sustainability Performance Management Practices on Organisational Sustainability Performance*, J. Account. Organ. Chang. 8 (2012), pp. 210–235.
- [24] B. Sezen and S.Y. Çankaya, *Effects of Green Manufacturing and Eco-Innovation on Sustainability Performance*, Procedia - Soc. Behav. Sci. 99 (2013), pp. 154–163.
- [25] S.P. Ganapathy, J. Natarajan, A. Gunasekaran and N. Subramanian, *Influence of Eco-Innovation on Indian Manufacturing Sector Sustainable Performance*, Int. J. Sustain. Dev. World Ecol. 21 (2014), pp. 198–209.
- [26] J.S. Keshminder and V. Chandran, *Eco-Innovation in the Chemical Manufacturing Firms : Insights for Policy Response*, Institutions Econ. 9 (2017), pp. 21–42.



- [27] A.N. Sarkar, *Promotion of Eco-Innovation to Leverage Sustainable Development of Eco-Industry and Green Growth*, Eur. J. Sustain. Dev. 2 (2013), pp. 171–224.
- [28] Y. Dong, X. Wang, J. Jin, Y. Qiao and L. Shi, *Effects of Eco-Innovation Typology on Its Performance: Empirical Evidence from Chinese Enterprises*, J. Eng. Technol. Manag. 34 (2014), pp. 78–98.
- [29] C.M. Luminea, J. Donovan and D. Tormey, *Application of Systems Simulation for Predicting and Optimising Energy Requirements for HDF Production*, J. Ind. Eng. 16 (2015).
- [30] B. Haleh. *Work Measurement Methods* Georgia, United States: Institute of Industrial & Systems Engineer, (2014).
- [31] D.W. Kelton, R.P. Sadowski and D.T. Sturrock, *Simulation with Arena*, Third Edn. McGraw-Hill Higher Education, New York, USA, (2004).
- [32] N. Diaz-Elsayed, A. Jondral, S. Greinacher, D. Dornfeld and G. Lanza, *Assessment of Lean and Green Strategies by Simulation of Manufacturing Systems in Discrete Production Environments*, CIRP Ann. - Manuf. Technol. 62 (2013), pp. 475–478.