A system dynamics approach to develop a recovery model in the Malaysian automotive industry

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Abstract. Design strategies play a significant role to enhance recovery effectiveness at the end of product life cycle. By reviewing previous study, there are many factors involved to enhance recovery effectiveness but limited to linking design strategies factors in holistic and dynamics view. Proposed method are explained and an initial model for end-of-life vehicles (ELVs) recovery model illustrated in graphical and numerical data is presented. However this is limited to authors understanding and preliminary data which requires collaboration between designers and other stakeholders to develop a model based on actual situation.

1. Introduction

Industrial growth for instance, Electronic equipment, Transportation, Chemical, Medical and pharmaceutical, Food and beverage, Consumer products, Materials production, Energy production and Services are examples of industries who runs economic activities to meet customers demand and are engaged with common challenges regarding sustainability issues. Statistic shows that manufacturers are the biggest contributor to merchandise trade activities which is USD 18,494 billion compare than commercial services which is USD 4,940 billion [1]. In 2015, total World Motor Vehicle Production is 90,780,583 (cars and commercial vehicles) which is an increase of 1.11% compared to 2014. Additionally, Asia-Ocean countries are leading in produced vehicles compared to other countries followed by America, Europe and Africa. China is the leading country producing vehicles in recent years and vehicles manufacturing in China increased by 3.15% in 2015. Similarly with Malaysia, total vehicles produced increased 3.18% in 2015. Malaysia was the third country leading in vehicles production in Southeast Asia after Thailand and Indonesia.

Malaysia automotive industry dominated by Proton (Perusahaan Otomobil Nasional/National Automobile Company) for 32 years since 1985 followed by 24 years ago for Perodua (Perusahaan Otomobil Kedua Sendirian Berhad /Second Automobile Manufacturer Private Limited). Even though this industry is growing well, they are required to follow the global legislation namely European Union Directive towards End-of-life vehicle (ELV) which is reuse and recovery should be achieved at 85% and 80% reuse and recycling [2]. In 2015, these target should be increase to 10% for reuse and recovery and 5% for reuse and recycling.
Currently, manufacturer are working on end-of-life vehicles issues to fulfill European Union requirement and take responsibility on their product after life span. There are many research on this issues to support automotive local industries towards these requirement. By reviewing previous research, there is a gap that must be fulfilled which links product design strategies towards recovery effectiveness. Thus, this paper is to propose A System Dynamics approach to develop a Recovery Model in the Malaysian Automotive Industry.

The rest of this paper is organized as follows. Malaysia automotive industry is presented in Section 2. System dynamics and initial recovery model are shown in Section 3 and finally recommendation and conclusion are presented.

2. Malaysia automotive industry
This section presents an overview on research and development to enhance ELVs management recovery activities in Malaysia automotive starting on 2009 to 2017 in general.

In recent years, there has been an increasing amount of literature on ELVs management to enhance environmental performance and in line with European Union directive. Malaysia is far behind compared with developed countries where the manufactured vehicles does not implement reusing components & parts into newly manufactured vehicles [3]. Additionally there are a lack of awareness regarding Design for environment (DFE) and Design for disassembly (DFD) among Malaysian stakeholders especially designers [4]. Numerous studies have attempted to explain how DFE is beneficial to the Malaysian automotive industry which will be presented next.

[5] proposed Fuzzy axiomatic design model to reduced recycling and disassembly cost by looking at weight, thickness and manufacturing cost. In the following year, these researchers focus on material section to enhance recyclability towards side mirrors. They proposed ABS, PET and PVC material because these material have good characteristics in terms of Low cost, high recyclability and lighter weight.

In 2012, [6] reported a simple replacement in the product material can lead a manufacturer toward producing more sustainable products. Similarly, Go et al. 2012 demonstrated that, Genetic Algorithm method provide a better disassembly sequences which leads to shorter disassembly time. They found that total disassembly time of the suggested sequence is less than the drafted sequence.

[7] focused on disassembly sequences, whilst [8] concerns on lightweight material selection for doors. These researchers found that for recyclability, aluminum and mild steel are recommended, while for light weight design, a combination of aluminum and carbon fibre are proposed.

In the view of ELVs management, [9] proposed framework for ELVs recycling management by Integrating 6R components in ELV framework. Similarly, [10] identified some ELVs management decision to minimize the environmental impacts and achieving economic benefits. In the same vein, [11] proposed Decision-Making Trial and Evaluation Laboratory (DEMATEL), Analytic hierarchy process (AHP) and fuzzy AHP (FEAHP). All of the studies are concerned on developing ELV management because it is important as initial starting for ELVs recovery activities for Malaysia automotive industry.

In 2014, Malaysia government introduced National Automotive Policy (NAP) as an outline to provide benefit among automotive industry stakeholders [12] and in line with European Union directive. Two years later, Malaysia Automotive Institute (MAI) launched 4R2S (Repair, Reuse, Recycle, Remanufacture, Service and Spare (replacement) parts) transformative plan toward automotive after-market industries [13] and [14].

A recent study by [15] examined factors in ELV management while [16] narrow the study to green supply chain factors and [17] look at how culture influences on choosing green product among Malaysian.

All of the studies reviewed here are summarized in figure 1.
Considering all of these evidences, there are many factors to enhance ELV recovery such as material selection, end-of-life (EOL) option strategies, disassembly sequences, management, supply chain and policy. Taken together, these studies support the notion that ELVs management is an important factors to enhance environmental performance by considering design strategies as a critical role in influencing ELV recovery effectiveness. These studies clearly indicate that there is a complex relationship among these factors and requires a dynamic approach to cater these complexity and dynamic changes such as demand, government policy and global regulation. This makes prediction of ELV outcome by designers to be very challenging to evaluate the best design strategies that should be implemented in order to meet government and European Union recovery target. Thus, this study proposes a holistic approach to evaluate design strategies by linking critical factors on ELV towards recovery effectiveness by gathering information from a variety of stakeholders such as manufacturer, distributors, collectors and policy makers.

3. System dynamics
System dynamics was founded by Jay Wright Forrester, who introduced the causal loop effect. The central idea of this approach is simulating the social behaviour, followed by designing effective policies in order to improve the system performance in reality [20]. There are two types of analysis used in system dynamics: (1) qualitative analysis (i.e. development of a causal loop diagram (see figure 2), and (2) quantitative analysis (i.e. development of stock and flow (see figure 3)). Both positive and negative signs are used in the causal loop diagram [21].

Figure 2 shows the relationships between the main variables of a model for spare parts [22]. We provide a succinct description of this model, as follows:
‘Sales of equipment’ is the starting point of this causal loop diagram, which is highlighted in bold typeface. The ‘−’ sign indicates that there is a decrease in the dependent variable when there is an increase in the independent variable. For instance, an increase in the delivery rate will decrease the order backlog. In contrast, the ‘+’ sign indicates that there is an increase in the dependent variable.
when there is an increase in the independent variable. For instance, an increase in the recovery rate will lead to an increase in the stock of serviceable spare parts. An arrow is marked with double lines if the variations of the independent variables will influence the dependent variables with significant delays. This will be the case if the organization increases its expenses for reverse logistics. The owners of the respective equipment may not give their responses immediately and return their obsolete equipment.

![Causal loop diagram for a model of spare parts](image)

**Figure 2.** Causal loop diagram for a model of spare parts [22].

### 3.1. Why system Dynamics?

Achieving sustainability is particularly challenging due to the complexity of the interrelated issues. For this reason, methods such as system dynamics are required to deal with these issues. Additionally there are six reason why these approach is selected and the reason is as follows:

1. System dynamics is an appealing technique since it can be used to analyse the relationships between many variables and improve the practicality of the Triple Bottom Line [23].
2. System dynamics is a powerful tool to analyse the behaviour of complex systems based on non-linear dynamic theory and feedback control.
3. System dynamics can be used to represent human behaviour as well as physical and technical systems and it is a specialized field that draws on cognitive and social psychology, economics and other branches of social sciences [21].
4. System dynamics enable one to identify the causal structure between variables for a given problem [24].
5. The qualitative and quantitative nature of system dynamics facilitates decision-makers during the decision-making process [25].
6. Causal loop diagrams provide clear information [26]; [27] as well as a holistic view of the entire system [28]; [29].

In general, previous study used these approach to cater ELVs recovery issues [30], [31], [32] and [33]. These is evidence that these approach have a high capability to handle complex issues such as product recovery startegies effectiveness.
3.2. Initial recovery model

Graph A represents recovery behavior as a result of this model, which different design strategies represent in different values (see B and see C in D if preferred in graphical values), how much recovery rate added in C by incorporating level, stock, and flow diagram (further explanation regarding level, stock and flow diagram refer [34]).

A – Presents a chart comparing recovery rate for design strategy in 4 quarters
B – Represents recovery percentage of 5 different design strategies
C – Shows percentage of recovery added annually and the total percentage of recovery added
D – Outlines the graph chart of the 5 design strategies

![Diagram](image)

**Figure 3.** Initial recovery model using system dynamics approach.

4. Conclusion and recommendation

Design for recovery is an important agenda to ensure that the objectives set in the National Automotive Policy are achieved and to alleviate the level of the Malaysian automotive industry to a global standard. This paper proposed system dynamics approach to linking product design strategies with other recovery factors to enhance recovery effectiveness in automotive industries. The technique proposed provides powerful tools to deal with complex issues such as product design strategies recovery effectiveness in evaluating interrelated factors and predicted outcome by decision makers. This is important to assist designers in evaluating the best design strategies and newly proposed model challenges in implementing recovery design to ensure that the process is sustainable and can be economically competitive.

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References

[1] OICA 2016 International organization of motor vehicle manufacturers Retrieved: August 20. 2016 from http://www.oica.net/
[2] Directive 2000/53/EC 2000 Directive 2000/53/EC of the European Parliament and of the Council on end of life vehicles (London: Department of Trade and Industry)
[3] Amelia L, Wahab D, Haron C C, Muhamad N and Azhari C 2009 J. Clean. Prod. 17 1572–79
[4] Ghazilla R A, Sakundarini N, Taha Z, Abdul-Rashid S H and Yusoff S 2015 J. Clean. Prod. 108 331–42
[5] Taha Z, Sakundarini N, Ghazila R A, Gonzales J and Abdul-Rashid S H 2010 Asia Pacific
Industrial Engineering and Management Systems Conf (Melaka: APIEM) p 1-8

[6] Ghadimi P, Azadnia A H, Yusof N M and Saman M Z 2012 J. Clean. Prod. 33 10-21
[7] Go T, Wahab D, Rahman M, Ramli R and Hussain A 2012 Expert Syst. Appl. 39 5409–17
[8] Sakundarini N, Taha Z, Abdul-Rashid S H and Ghazila R A 2013 Mater. Design 50 846–57
[9] Azmi M, Saman M Z and Sharif S 2013 Proc. of the 11th Global Conf. on Sustainable Manufacturing - Innovative Solutions (Berlin: Universitätsverlag der TU Berlin) 187-93
[10] Ahmed S, Ahmed S, Shumon M R and Quader M A 2014 J. Appl. Sci. & Agric. 9 227-37
[11] Ahmed S, Ahmed S, Shumon M R, Falatoonitoosi E and Quader M A 2016 Int. J. Sust. Dev. World. 23 83-97
[12] NAP 2014 National Automotive Policy Malaysia
[13] MAI 2016 Code of practice for motor vehicle aftermarket: repair, reuse, recycle and remanufacture (4R) for parts and components (Cyberjaya: Malaysia Automotive Institute and SIRIM Berhad)
[14] MAI 2016b Code of practice for motor vehicle aftermarket - service and spare (replacement) parts (2S) (Cyberjaya: Malaysia Automotive Institute and SIRIM Berhad)
[15] Mamat T N, Saman M Z, Sharif, S and Simić V 2016 J. Clean. Prod. 135 1289-97
[16] K S M, Abdul-Rashid S H and E U Olgu, R A R Ghazilla 2015 I. E. 22 46-61
[17] Ghazali I, Abdul-Rashid S H, Dawal S Z, Aoyama H, Tontowi A E and Sakundarini N 2017 Cultural influences on choosing green products: an empirical study in Malaysia Sustainable Development
[18] Taha Z, Sakundarini N, Abdul-Rashid S H, Gonzales J and Ghazila R A 2011 Int. Conf. on IML 1-7
[19] MAI 2017 4R2S Industry Standards Cyberjaya, Selangor, Malaysia.
[20] Lane D C and Sterman J D 2011 Profiles in Operations Research: Jay Wright Forrester in A A Assad and S I Gass, Profiles in Operations Research (New York: Springer) 363-86
[21] Sterman J D 2000 Business Dynamics System Thinking and Modelling for a Complex World. (Boston: Burr Ridge: McGraw-Hill)
[22] Spengler T and Marcus Schröter 2003 Interfaces. 33 7-17
[23] Lee S, Geum Y, Lee H and Park Y 2012 J. Clean. Prod. 32 173-82
[24] Byggeth S H, Ny H, Wall J, Broman G and Robért K H 2007 Int. Conf. on Engineering Design (Paris: Cite Des Sciences Et De L’Industrie) p 1-11
[25] Galanakis K 2006 Technovation. 26 1222–32
[26] Sumari S, Ibrahim R, Zakaria N H and Hamid A H I. J. M. E. 1 54-9
[27] Tan B S and Yap E H 2015 J. E. S. T. 10 1150-61
[28] Hjorth P and Bagheri A 2006 Futures. 38 74–92
[29] Kasperek D, Lindinger M, Maisenbacher S and Maurer M 2014 Paris DSM 14 Proc 234-42
[30] Georgiadis P and Besiou M 2008 J. Clean. Prod. 16 1665–78
[31] Halabi E E and Doolan M 2012 Int. Society for the Systems Sciences 1-16
[32] Wang Y, Chang X, Chen Z, Zhong Y and Fan T 2014 J. Clean. Prod. 74 161-71
[33] Kumar S and Yamaoka T 2007 J. M. T. M. 18 115-38
[34] Richardson G P and Pugh A L 1986 Introduction to System Dynamics Modeling with DYNAMO (London: The Massachusetts Institute of Technology)