Analytical analysis for material efficiency practice: an exploratory study of Malaysia manufacturing cases

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Abstract. Practicing material efficiency in the manufacturing industry is gaining a high interest among the practitioner due to increasing material cost and the rise of industrial solid waste issue. However, not all type of manufacturing company is being studied of their material efficiency initiatives and strategies. In this study, we examined the material efficiency strategies in two selected manufacturing case companies - 1) Wire and Cable Company, 2) Automotive Glass Company. Qualitative methodology was used to explore their material efficiency insights such as drivers, challenges, and also the proposed material efficiency strategy. This study has drawn out the experiences of both companies on material efficiency strategy adoption. Analytic frameworks are developed for both case companies to practice material efficiency strategy. Perhaps, the derived insights and frameworks could work as a reference to aid other manufacturing company in constructing their favorable solutions to achieve material efficiency.

Keywords: Sustainable manufacturing, material efficiency, resource efficiency, waste minimization.

1. Introduction
To date, human has consuming the earth resources far faster than regenerating and sustaining it. The rapid growing of world population has posts drastic changes to the resource consumption, particularly, two times consumption rate comparing to the past decade [1]. For example, to fulfill the customer needs, manufacturer needs to consume more materials to turn into finish goods [1-2]. As a consequent, material scarcity and great environmental impacts may occurs due to high materials demand, high energy consumption across the manufacturing activities, poor material recovery activity, and fast growing of solid waste especially from the manufacturing sectors.

Practicing material efficiency strategy can contribute significant reduction to the material usage and also generate less solid waste [1, 3-4]. From the past studies, different manufacturing sectors practice different solutions to achieve material saving and reduce solid waste generation. For example, paper industry reducing their paper thickness in order to enhance material usage [5], metal industry encourage
of by-products recycling to recover the metal scrap [1], electrical and electronic industry combining their product features to reduce their product weight and size [6]. Nevertheless, the available material efficiency solutions from these studied manufacturing cases may not suitable to apply into other industries which has different product design, production setting, product requirements, and business orientation. Therefore, there is a necessary to conduct investigation into different type of manufacturing industry, particularly to understand their practices in perceiving material efficiency concept.

The purpose of this study is to explore the potential material efficiency strategy and its influencing factors from manufacturing case companies in Malaysia. This paper is structured as follow sections: introduction, literature review, research methodology, results, case study discussion, research implications, and conclusion remarks.

2. Literature review
As fundamental, material efficiency is defined as use less of material for delivering similar functions or output [1-3, 7]. In the manufacturing sector, manufacturer practicing material efficiency to reduce material intake and to reduce solid waste generation [1-3, 6-7]. In some extends of material efficiency concept, other scholars emphasized material efficiency should include of reduction of energy usage, reduce of chemical substances along the manufacturing process, and enhance the material recovery rate during product end of life phase [7-9].

Based on the existing material efficiency frameworks and models [1-3, 7], material efficiency can be achieved through product design and also manufacturing process. In product development phase, achieving material efficiency can be done by designing the product with less or product light-weighting [1]. For instance, by reducing the total product parts, it can reduce the product weight with fewer assembly parts. In term of material intake, material substitution is a common yet effective strategy to achieve material efficiency. Lilja [2] encouraged of green material substitution to reduce the potential environmental impacts caused by the hazardous substances. In addition, product designer needs to consider of raw material intake that able to ease and shorten the manufacturing process such as the use of pre-fabricated raw material [6], use of materials that ease to be recycled [9].

Furthermore, the designer is urged to practice design for 3Rs (reduce, reuse, recycle) to ensure more materials are saved and recovered when it reached its end of life. The purposes of these activities are to extend the life of the product, and reduce the virgin material extraction for producing a new product. From the past studies [1-3], design for longer life is another practice to achieve material efficiency. The designed product should consist of features of serviceable or repairable, ease to upgrade, and also build from tough materials to avoid short life cycle. However, in some type of product such as electronic goods, the short life cycle of product design can’t be avoided due to the fast fashion changes in product [3].

Achieving material efficiency in manufacturing processes can be seen from the context of process efficiency, yield improvement, by-product recycling, and also green packaging [1-3]. Lilja [10] stated that process efficiency in manufacturing phase is able to reduce the manufacturing time such as batch processing, process substitution. One of the examples of the process efficiency is switching the conventional machining process to metal casting. Yield improvement is another important element to optimum raw material usage. The obvious activity to reduce the yield is by using prefabricated materials to simplify the manufacturing process, and reduce the potential errors of goods to be wrongly fabricated. Another option to achieve yield improvement is to acquire advanced technologies with better fabrication efficiency and precision control such as laser cutting machine. In by-product recycling context, Pajunen et al. [9] commented the used materials could be saved by collecting the scraps and practice internal recycling or sell to authorize recycler. As for green packaging, the main concern in on the aspect of utilizing the recyclable material for packaging which is environmental friendly such as recycled based substances [9, 11].
In drivers to practice material efficiency, there are six general drivers namely reducing material consumption [1-3], reducing solid waste [1-3,7], rise of material cost [1-3,7-9], reduce environmental impact [1-3,7-9], reduce energy [1-2,5,8], to fulfill the regulations and policy [1,3,7,10]. These drivers appear as common drivers that able encourage a company to enhance their material consumption.

Whereas, in challenges context, manufacturers claimed they are facing problems on how to utilize their material efficiency. For example, these challenges are technology limitation [1,4,9,13], lack of knowledge particularly in product design [1,4,8,13], rapid changes in customer requirements [1,8-9], regulation and policy requirements especially in environmental requirements [1-2,10].

3. Research methodology

In this study, a qualitative based investigation or semi-structured interview was conducted to explore the real-time, insights, and unique data from the industry informants [14-15]. There is two different types of case company have participated in this study: 1) Wire and Cable Company, 2) Automotive Glass Company. To ensure the quality of data collection, only experienced key-informants were selected to participate the interview session (see Table 3.1). The face-to-face interview was conducted during the data collection, while sites visit also being carried out to verify the interview contents with the real working environment. The examples of the interview questions are shown in Appendix 1.

| Company origin                  | Activities involved                                                                 | Informants                  |
|--------------------------------|-------------------------------------------------------------------------------------|-----------------------------|
| Wire and Cable Company          | • Manufacturing and laying cables for telecommunication sectors, commercial industry plant, building construction. EMPLOYEE: 300 (Malaysia) | • Production Manager        |
| Italian-based multinational corporation (ISO14001 compliance) |                                                                                   | • Senior Designer           |
|                                |                                                                                   | • Purchaser                 |
| Automotive Glass Company        | • Automotive glass design, manufacture of glass products EMPLOYEE: 430 (Malaysia)  | • Production Coordinator (Manager) |
| UK based company                |                                                                                   | • Planning manager          |
| (ISO14001 compliance)           |                                                                                   |                             |

3.1. Data Analysis

In this study, thematic analysis was used to analyse the taped-recorded interview data [16]. From the taped interview recording, there are 22 pages of verbatim transcribes were generated: 10 pages from Wire and Cable Industry, 11 pages from Automotive Glass Industry. Authors were repeated study the transcripts in order to get familiar with the data. Next, data reduction was performed by selecting only significant quotes and phrases during the initial stage of data analysis. From all collected potential related quotes, it was sorted and rearranged according to a similar data group. This step is important to ensure there is no redundancy of data recorded and to avoid confusion of selected quotation. In the final data analysis, a theme was given to the formed categories based on codes’ suitability. Several rounds of member checking were also conducted with other research members to ensure the sorted quotes are interpreted consistently [16]. From the extracted insights, it was classified to build into an analytical framework for each case.

4. Results and discussion

4.1. Material wastage in Wire and Cable Company

According to the interviewee, along the wire and cable manufacturing process, there are four types of solid waste could be found: 1) Copper dust during the copper drawing process, 2) By-products of cable during the machine setup and changing of the raw materials, 3) Irregular shape of cable during the
Polyvinyl chloride (PVC) extrusion process, 4) Failed cable product during the final quality inspection and testing.

4.2. Material efficiency drivers in Wire and Cable Company
In the aspect of drivers to practice material efficiency, the main drivers to practice material efficiency in wire and cable company is reduce production cost, especially to produce a cost efficient product. Besides, Wire and Cable Company also trying to reduce their product scraps generation, which may directly give impacts to the environment, and cost to invest for waste management. In addition, by using the better quality of material, less rejection of finish goods could be achieved. Meanwhile, the studied cable company also certifies to the ISO 14001 standards in order to ensure their manufacturing processes are fulfilling the environmental requirements such as less emission release, reduce hazardous chemical use, etc. These initiatives are important to enhance the company competitiveness and improve the company environmental image.

4.3. Challenges faced by the company in Wire and Cable Company
Manufacturing of cable and wire product has posed many challenges in the context of material efficiently use. From the interview, we are informed that the technology limitation is one of the major problems in this company, whereby most of the used machines are old and outdated. Therefore, the possibility of product failure to happen is higher, and it may decrease the company productivity. Furthermore, old technology did cause the reliability issue in producing the same dimension of cable especially the extrusion of PVC.

Besides, many of the cable manufacturing processes are required the manual operations from the skilled worker. However, across the interview, we have clarified that not all the operators are skilled, whereby some of them may have the problem to operate the machines. In that sense, the lack of knowledge could cause more waste generation due to human mistake. Another issue faced by the company is the uncertain of product orders which may increase the material waste due to machines are required to do the setup in more frequent. In product design context, change in cable technology is limited, therefore the company is facing less product design constraint whereby for any integration such as to embed environmental element into the product design still appeared not the main priority.

4.4. Proposed solutions to achieve Material efficiency strategy in cable and wire company
To enhance the material efficiently use, there are two main scopes of activities proposed by Wire and Cable Company namely material sourcing and optimizing the manufacturing process.

4.4.1. Material sourcing
Source for good quality of raw material in cable manufacturing can reduce the potential of product failure and generate less solid waste. Meanwhile, the company also practicing good collaboration with their supplier in order to achieve material saving. For example, pre-manufactured raw material purchase such as the copper rod in a specific diameter and cut length to ease the manufacturing process. By doing so, the potential waste to be generated such as copper dust can be reduced.

4.4.2. Manufacturing process
Manufacture phase in cable industry generated the most solid waste. Examples of solid waste are the by-products from the strapped cable during the machine setup and also during the product packaging. Therefore, improve on the product changeovers for the different type of wire products, which could potentially reduce the materials to be wasted during initial setting.

Improving the process planning wire variants could also reduce the material scrap due to less machine setup to be conducted. Other solutions have been proposed to encounter this problem such as practicing by-product recycling which is done by external recyclers, and also product reuse. The by-products such as copper rods will be collected and sell to the recycler, while the semi-failed goods will be reused into the production lines. Besides, the company does utilize of automatic monitoring and control system to
ensure the consistent pattern of extrusion process is performed, and this improvement is able to reduce the product failure during the jacketing extrusion process. Besides, in material preparation, the wire and cable company does practicing process efficiency to reduce the rate of machine setup because, for each machine setup, it may generate a certain amount of solid waste. Wire and Cable Company is highly depending on the skilled worker to handle and monitor the manufacturing processes. Therefore, improve the operator skills could reduce the human mistakes occurred especially during material handling and also operating the machines.

Figure 4.1 shows the analytic framework to practice material efficiency in wire and cable industry. From the framework, it shows the summary of activities and processes involved to produce wire and cable, material efficiency strategy conducted, and also the factors that influence material efficiency such as drivers and challenges.

4.5. Material wastage in Automotive Glass Company
The solid waste generation in automotive glass industry can be found mostly during the manufacturing process such as: 1) by-products during material setting, 2) rejected product (poor quality products), 3) off cuts materials during machine setup, 4) damaged products due to miss-handling.

4.6. Material efficiency drivers in Automotive Glass Company
Glass products are less restricted in term of the product design because it was mainly made from abundant materials and biodegradable resources, e.g. silica sand. For automotive glass manufacturer, the main drivers faced by automotive glass industry are referring to gain high profit, fulfill the customer requirements by producing a high-quality product, and also to reduce the material waste due to the improper material handling and high product yield. Besides, reduce the energy usage also playing an important role to encourage the glass manufacturer to achieve material efficiency.

4.7. Material efficiency challenges in Automotive Glass Company
In material efficiency context, the main challenges faced by automotive glass company are the high energy consumption of the manufacturing process. The energy usage is high due to continuous heating process in the furnaces. The second barrier is the high yield of production. The control of yield will become a great challenge for the manufacturer especially to produce automotive glass with different requirements. The glass scraps are mainly generated during doing machine setting for different specification of glass. On the other hand, to produce the automotive glass products, there are 5-10% of raw glasses to be scraped in order get the exact shape during cut to size process. From the interview, we are informed that automotive glass company still using conventional machinery, therefore the available technology limitation, especially the jigs, may decrease the efficiency of material to be processed.
4.8. Proposed solutions to achieve material efficiency in Automotive Glass Company

To enhance the material efficiently use in automotive glass company, there are two main scopes of activities have been proposed namely material sourcing and manufacturing process.

4.8.1 Improve the properties of raw material

The raw materials used to fabricate glass are mainly sand or poly-silicon. The sources used are cheap, abundant, and easy to acquire. Therefore, recycle used glass is still not widely being practiced among the practitioner due to the quality issue of recycled material, and also high energy consumption. But, one of the common issues arise is the product failure due to vibration or improper handling. Therefore, improving the material properties of the glass could enhance the quality of product and reduce product failure. Besides, add in catalyst could strengthen the glass structure and reduce the potential of products failure could help in achieving material efficiency. It could help to reduce breakage of the glass during handling.

4.8.2 Manufacturing process

The main issue faced by automotive glass industry is the high energy usage during the manufacturing process. Therefore, reducing the energy usage by adopting automatic temperature control system may aid to decrease total energy usage. In addition, the company also suggested to avoid high energy consumption, the company is practicing 24 hours operation basis to achieve energy efficiency especially
to shorten the time to reheat melting chamber. If the heating machines are shouting down frequently, more energy may require and this may increase the operation cost.

4.8.3 Manufacturing process
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In machine setup aspect, the manufacturer could standardize and simplify the setup procedures in order reduce product scrap due to different product specifications. Effective production planning especially to reduce changeovers sequence could help in reducing the material wastage due to testing purpose. Meanwhile, an improvement on the jig and fixture should be studied to enhance cut to size of the automotive glass, and reduce secondary process such as trimming the glass which could potentially generate scrap, reduce productivity, and also cause product damage.

Automotive glass manufacturing process is semi-controlled by the human forces. Therefore, the need of skilled worker is highly demanded. In parallel, the product failure due to human factors may increase. For that reason, the use of automation system is proposed in the production lines. With these changes, it is believed that the waste generated due to a less human error such as misplacing of product, mis-handling of the product can be reduced.

Figure 4.2 shows the analytic framework to practice material efficiency in automotive glass manufacturing industry. The framework presents the activities of glass manufacturing process, influencing factors, and material efficiency strategy along the process of automotive glass fabrication.
5. Research implications
In this study, the opportunities to enhance the material use are clarified through two different types of manufacturing companies. An analytic framework was established for each company to enable a clearer view of the material efficiency solutions.

For Wire and Cable Company, the purchase of cut to size copper rod could ease the manufacturing shorten the wire drawing process. Material efficiency improvements can be achieved on the aspects of effective planning for the changeovers activities to minimize the machine setup for different variants of products. Besides, the use of an automatic control system to ensure the stable flow of materials is another important solution proposed to reduce the material waste due to the unreliable extrusion process. Recruit of the skilled workers are needed to ensure less production issue especially the wire drawing process and also inner and outer jacketing process. In addition, good communications and training must be conducted to avoid unnecessary problem occur such as improper machine setting, product failure due to material mishandling.
As for the Automotive Glass Company, the main improvement is to upgrade the existing melting furnace with dynamic temperature control capability. The purpose of establishing a dynamic control system is to reduce energy utilization during machine setup and heating process. The second improvement needs to focus on redesign the available jig and fixture to ensure minimum clamping edge can be achieved. This improvement is important to ensure less material wasted due secondary process and high product yield especially for testing units and also damage to the product. Similar to Cable and Wire Company, the uses of skilled workers are also important in automotive glass industry especially to handle the end product. On the other hand, by introducing the automated handling system can aid the worker and reduce the potential of product damaged due to mishandling of the product, but it is costly comparing to use a skilled worker. Lastly, an add-in of catalyze substances into the raw materials preparation to strengthen the products material properties. By doing so, it could improve the glass durability and strength to against product breakage and failure during product handling.

For both companies, although they are producing two different types of products with a different process, but they are sharing many similarities especially in influencing factors. For example, both companies are strongly driven by the market requirements. Both company’s products are not required to comply with any stringent environmental standards specifically for metal or glass industry. However, high energy consumption during manufacturing process could be their challenges. Technology limitation and improvement of the worker skills could become their priority considerations to achieve material efficiency. The only difference was noticed in both cases are the by-products from cable and wire company is recyclable, while a scrap of automotive glass is not advisable to be recycled use due to the cheap raw material cost and material properties may change after recycled for other purposes.

5.1. Material wastage in Wire and Cable Company

According to the interviewee, along the wire and cable manufacturing process, there are four types of solid waste could be found: 1) Copper dust during the copper drawing process, 2) By-products of cable during the machine setup and changing of the raw materials, 3) Irregular shape of cable during the Polyvinyl chloride (PVC) extrusion process, 4) Failed cable product during the final quality inspection and testing.

6. Conclusion

In long term business running, material efficiency has becomes a significant concern for today’s manufacturing company. This paper illustrates the pathway and concerns of two manufacturing companies in perceiving material efficiency strategy.

In this study, we understood that both case companies complied with an ISO14001 environmental management system for effective waste management, energy usage, and also CO2 emission control. The end products of both companies are rather straight forward without any requirement of assemblies. Therefore, one can be noticed of the initiative in material efficiency are more on the improvements of manufacturing activities, while less product design changes can be made to improve material efficiency. For instance in Wire and Cable company, the common practices are optimizing the product changeovers, pre-cut material purchase, improve material quality, improve the labor skills, by-product recycling, and also the use of automatic monitoring system. As for automotive glass company, material efficiency can be achieved by reducing energy usage, use of automation system, optimization in product changeovers, and also close to machining tolerance setting.

Although the fabrication processes for both companies generate less solid waste, but their manufacturing process consuming high energy and creating high CO2 emission. Unsurprisingly in achieving material efficiency, both companies are driven by concern of reduce materials consumption, reduce product scrap due to machine setting and product handling, and also less energy consumption. As for the challenges faced, there are three main barriers clearly seen in both industries: high energy consumption, poor machine and material setup, and also the issue of skilled labors.
Effective material utilization relies on the type of business and company competitive drivers. Therefore, it is difficult to ascertain material efficiency strategy for the different type of manufacturing company. In this research, considerably material efficiency strategies were discovered to improve the material utilization in two different type of companies. This paper extends the literature of material efficiency research by providing insights data from different manufacturing companies in Malaysia context. Although the obtained data are limited, but the data were studied with very careful to enable unique findings to emerge. Thus, the findings obtained in this study are able to provide a useful and quick reference to support the similar manufacturing sectors in achieving material efficiency.

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Appendix 1- Interview protocols
1. What are your company drivers to practice material efficiency strategy?
2. What are your company barriers/challenges to practice material efficiency strategy?
3. What are your company solutions/strategies to achieve material efficiency?
4. Is there any strategies proposed to reduce material usage? If yes, how?
5. IS there any strategies proposed to reduce solid waste generation? If yes, how?

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