Measuring Sustainability Performance in the Product Level

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Abstract: Sustainability is becoming increasingly important in new product development as modern society demands technicality, customer satisfaction, and economic efficiency during a product's life cycle. Previous papers have commented more on the environmental aspects of sustainability in project management, whereas less attention has been paid to the measurable indicators of products. The knowledge about the product process structure is beginning to use sustainability indicators as part of the approach. Based on this idea, this paper suggests a combination of measurable indicators of sustainability that can be used in the product process structure of the construction industry. The aim is to identify a product process structure that is compatible with sustainable project management. The idea of product design structure matrix (DSM) will be introduced to identify the sustainability of products. By analysing the different dimensions of the measurable indicators, the sustainable products can be compared. This provides an integrated view of the product process structure when developing new products. This approach will then be applied to the smartphone industry as an illustrate example, which will provide ideas to improve the sustainability of new smartphone development.

1 INTRODUCTION

Sustainability has been a major source of discussion for some years. Shareholders use the term 'sustainable' to describe their products and activities. They all state that they are trying to protect natural resources and the global environment. Indeed, the manufacturing industry has actually been achieving some form of sustainability (Eskerod and Huemann, 2013). The creation of high-quality products at competitive prices is what makes manufacturers profitable. As a result, throughout history, manufacturers have been trying to find ways to make the machining process more efficient and cost-effective, including the continuous development of advanced and sophisticated production machinery and improved cutting tools, and the optimization of the entire cutting system (Silvius and Schipper, 2014). Specific strategies that have been developed include high-speed, high-feed, high-performance, and digital machining.

Sustainability is generally divided into three dimensions: economic, environmental, and social. In the manufacturing factory, the sustainability of the production process and the sustainability of the conveyance are both essential as they can have significant social and environmental effects (Pimmler and Eppinger, 1994; Browning, 2001). A sustainable product process structure is specifically relevant for industries that have a large output with a lot of waste. In the multi-product life cycle, it is also a system that is turn to concentrate on sustainability, but the absorption is more on the environmental dimension of the product itself. Sustainability has dominated international attention, due largely to the society that unfavorable environmental effect is increasingly concentrated (Ma and Kremer, 2016; Okudan et al., 2013).

Sustainability is an essential project purpose equilibrating other aspect of costs and earnings. Sustainability in the production process means the use of practices that ensure the process is economically, socially and environmentally acceptable throughout its life cycle (Silvius and Schipper, 2014). Sustainable project management relates and develop on stakeholder pattern (Eskerod and Huemann, 2013), includes life cycle considerations and development

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(Labuschagne and Brent, 2005), and ensures the three dimensions' measurable indicators of sustainability are adhered to products (Silvius and Schipper, 2014). Klakegg (2009) implied different thinking for the demand of sustainability in project management: lack of interest, lack of participation from main stakeholders, low profits of sustainability compared to the required investment, and dynamic environment.

The relationship between sustainability and the product is being discussed in an increasing number of papers (Silvius and Schipper, 2014; Aarseth et al., 2017), with 'green' or 'sustainable' products having been determined as one of the most important international topics (Alvarez-Dionisi et al., 2016). Product development activities typically begin by recording customers' requirements and society's demands (Eppinger et al., 1994; Browning, 2001).

By investigating the production process in the manufacturing industry, decision makers can determine the sustainability of different products. The product design structure matrix (DSM) is a matrix-based analytical method created by Steward (1981) and developed by Pimmler and Eppinger (1994) to aid with multi-project management. A matrix representation is also used to indicate different manufacturing of three dimensions (Pimmler and Eppinger, 1994). Furthermore, in the project process structure, developments in manufacturing industry have been indicated as communication system of interacting new product that generate their profits for more earnings (Sosa et al., 2004; Cataldo et al., 2006).

2 MEASURABLE INDICATORS OF SUSTAINABILITY AND THE MANAGEMENT LIFE CYCLE BASED ON PRODUCT

2.1 Sustainability of the Product Life Cycle

Sustainability based on the production process structure is a comprehensive, time-based method, which indicates the structural performance based on the three measurable indicators of sustainability throughout the product's life cycle. A life cycle analysis has the ability to evaluate the social, economic, and environmental impacts of the product process structure throughout its entire life cycle, allowing it to determine the most suitable product that meets a customers' needs.

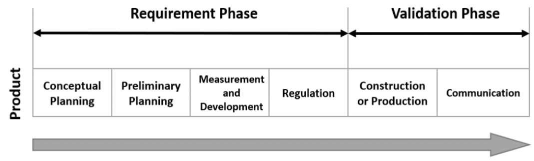

Figure 1: Sustainability of the Product Life Cycle.

The main goal for developing a new product is to design a product or to alter the production industry to meet the demands of the customers. The procedure phase of the product life cycle is in the product of the manufacturing industry (Silvius and Schipper, 2014). In recent years, product life cycles have played an essential role in life cycle assessments (LCA), which are used to estimate the performance of different products. An LCA examines six stages in a product's life cycle. These stages (conceptual planning, preliminary planning, measurement and development, regulation, construction or production, and communication) are split into two phases: the requirement phase, and the validation phase. The difference between these two phases is that the first focuses on the supply chain, and includes the planning and measurement of a product, while the second starts the life cycle of a product with the construction in industry and includes the supply chain activities as part of the validation phase.

In the requirement phase, measurement indicators are used to give guidance to for initial planning and regulation. In the validation phase, measurement indicators are used for production and final coordination.

2.2 Identifying Indicators That Can Be used to Measure the Sustainability Evaluation Criteria

Some researchers include three dimensions of sustainability jointly in product selection. Labuschagne and Brent (2005) specified three aims of a sustainable product process structure, including social equity, economic efficiency, and environmental performance. They stated that sustainability is a compound term, including social, economic, and environmental aspects. The three dimensions of sustainability for an enterprise are people, income, and earth, each of which represents the social, economic, and environmental aspects in turn (Daneshpour, 2016). Each dimension includes many different measurable indicators. Table 1, 2 and 3 list the three dimensions (economic, environmental and social) of these measurable indicators.

Table 1: Economic Indicators of Sustainability for Products in the Manufacturing Industry.

Economic Indicator	Description
Indicator A: Level of Stakeholder involvement	Satisfying stakeholders' needs and interests by involving them in the development of the project, leading to the successful delivery of projects.
Indicator B: Financial performance	Financial performance: An objective measure that concerns the return on investments, and the creditworthiness, viability, and cash flow of a project.
Indicator C: Sustainable pricing	Every business faces the challenge of setting sustainable prices for its goods or services. The price must be high enough to cover costs and generate profit, but must still be low enough to attract customers in a competitive market.
Indicator D: Customer satisfaction	Customer satisfaction is a key element for sustainable economic development. What customers care about is when their order will be delivered. Customers start to calculate the delivery date as soon as the order is placed. The delivery time does not just include the production time.

Table 2: Environmental Indicators of Sustainability for Products in the Manufacturing Industry.

Environmental Indicator	Description
Indicator E: Waste and measurement	To reduce waste and save resources, it is necessary to understand the characteristics of the material being used and the processing technology.
Indicator F: Reducing energy consumption	Sustainable processing can minimize the energy consumption per cubic millimeter or cubic inch of material. Minimizing energy consumption will reduce energy waste and make the processing process more environmentally friendly.
Indicator G: Level of environmental responsibility	This indicator refers to the equity between members of different generations, and to their ability to cooperate to improve the quality of the environment.
Indicator H : Correlation of the life cycle of products and services to reduce environmental impacts	This indicator is measured through a lifecycle analysis, a product disassembly analysis, post-sale tracking, and reverse logistics.

Table 3: Social Indicators of Sustainability for Products in the Manufacturing Industry.

Social Indicator	Description
Indicator I: Social responsibility level	It refers to competition and pricing policies, compliance with anticorruption practices and contribution to social campaigns.
Indicator J: Sustainable levels of employment	This indicator concerns the empowering of young people through the provision of better job opportunities, the creation of environmentally friendly jobs, and the conditions needed to create them.
Indicator K: Level of Social impact	This indicator is measured through an analysis of the statistics showing society's views of a specific project.
Indicator L: Public acceptance towards a product	This indicator refers to the willingness of society to embrace a product or service.

The economic dimension focuses on increasing profits, minimizing expenditure, and increasing income (Huntzinger and Thomas, 2009). The main goal of a project is to make profit for the shareholders. Brones and Carvalho (2015) stated the importance of the economic dimension, as it protects the assets of the shareholders. As a result of the shift from a commodity exchange system to a currency-based economy, organizations and individuals need money to obtain the resources they need. Expenditure in investment in an enterprise ensures growth in the manufacturing industry invested into the enterprise to make sure that the manufacturing industry arrive growth. The economic aspect of sustainability is commonly used in product selection. Profitability is more important than returns or expenditure, although there are many other indicators that can be used to measure this aspect.

Environmental sustainability is primarily concerned with the protection of the environment (Gore, 2006; Higgins, 2010). The environment has been adversely affected by the processes that have been developed by people (Gore, 2006; Higgins, 2010; Ludwig et al., 1993). Environmental protection needs to be included as part of product selection. Researches initiate to connect environmental assessment into product, such as manufacturing industry (Labuschagne and Brent, 2005). In most cases, environmental demonstration is integrated as a condition to approve decision-making in the product.

The social dimension involves the ownership in which enterprise manipulate as well as the workers of the enterprise (Dempsey et al., 2011). The workers are the people who produce the consequences of the industry and should be valued by the shareholders. The products of the enterprise are also reliable on how the society influence the enterprise (Harik et al., 2015). However, social sustainability deserves much more attraction, as it focuses on daily life and has an important effect on society. There are four indicators that can be used to measure social sustainability: social responsibility, sustainable employment, social impact, and public acceptance of the product.

3 BUILDING A SUSTAINABILITY EVALUATION MODEL BASED ON DESIGN STRUCTURE MATRIX

3.1 A Structured Approach to Identify and Validate Selective Products

In order to rank the sustainability of different products in the manufacturing industry, this paper introduces a five-step approach to identify and validate selective products, split into two phases (see Figure. 2). The first phase (steps 1, 2, and 3) focuses on identifying selective products based on the measurable indicators, and then examines the sustainability of the selected products (Ghadimi et al., 2012). The second phase (steps 4 and 5) focuses on validating the products identified during the first phase by comparing them in order to determine the most sustainable products. The introduction of the product DSM (P) in step 2 is fundamental to this approach, as it allows data on the measurable indicators to be captured.

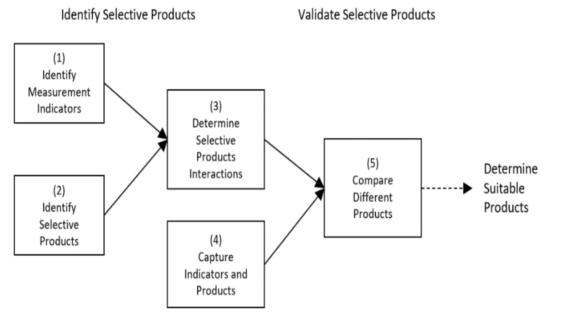

Figure 2: A Structured Approach to Identify and Validate Selective Products.

The basic assumption behind this the first phase of the approach is that selective products between measurable indicators generate coordination requirements. The first phase focuses on identifying the set of interactions that could, potentially, take place to coordinate the selective products that are being measured.

In order to determine the most sustainable product, it is necessary to identify the sustainability of each of the selected products. This type of product network is identified by asking the product developers (m) about their level of involvement in the design of each of the product components (n). This information is documented in the product DSM (P). P_{mn} is a rectangular matrix, in which the m rows are labeled with the selected product and the n columns are labeled with the measurable indicator. Cell a_{mn} indicates the degree of involvement of product i in the design of indicator j. The rows are ordered based on the formal organisational structure, with the individual developers split into groups so that group members are sequenced together.

The selected product matrix ($P_{selective}$) can be defined as a function of the product DSM (P) as follows:

$$P_{selective} = P^T P \tag{1}$$

The product DSM (P) can be used in a similar way to determine the number of measurable indicators to whose determine products contribute. In such a case, the rows within the product DSM should be compared, so that $a_{ik} = a_{jk} = 1$ if both products i and j meet the measurable indicators. In this manner, the selected product interaction matrix ($T_{selective}$) can be defined as follows:

$$T_{selective} = PP^T \tag{2}$$

To determine the sustainability of products i and j, the entries of both the measurable indicator Domain Mapping Matrix (DMM) (M) and the product DSM (P) need to be examined. More specifically, product i would look for sustainability from product j ($t_{ij} > 0$) if indicator K influencing product i ($a_{ik} > 0$) depends on indicator L ($p_{kl} > 0$) which is influencing product j ($a_{jl} > 0$). Therefore, ($t_{ij} > 0$) if ($a_{ik} > 0$), ($p_{kl} > 0$), and ($a_{jl} > 0$). Moreover, if M and P are binary matrices, then the number of times that products i and j need to coordinate measurable indicators interfaces between products to which they contribute needs to be measured. In other words, the number of times that a_{ik} = p_{kl} = a_{jl} = 1 needs to be counted for products i and j. This can be determined using the following equation:

$$t_{ij} = \sum_{k=1}^{n} \sum_{l=1}^{n} a_{ik} p_{kl} a_{lj} \tag{3}$$

Once this has been done, the validate product matrix ($T_{validate}$) can be formally defined, allowing it to record the relationship between the selective products with sustainability. This matrix is a function of both the product DSM (*P*) and the measurable indicator DMM (*M*). The validated product matrix can be generated using the following equation:

$$T_{validate} = PMP^T \tag{4}$$

3.2 Determine the Sustainability Evaluation Model

To illustrate the rationale behind Equation (4), Figure 3 shows the measurable indicator DMM (*M*) for the 12 indicators that can be used to compare the similar products in the manufacturing industry which were identified by the product DSM (*P*). The product PM produces a rectangular matrix in which non-zero cells capture the number of products with which product I is involved, imposing sustainability constraints on product j. The $T_{validate}$ can be estimated in the end for further analysis.

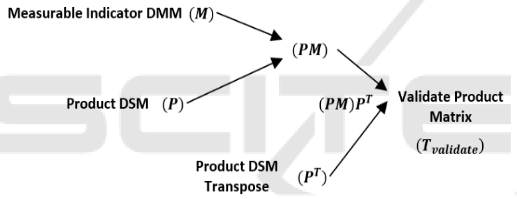

Figure 3: Sustainability Evaluation Model.

	Indicator A	Indicator B	Indicator C	Indicator D	Indicator E	Indicator F	Indicator G	Indicator H	Indicator I	Indicator J	Indicator K	Indicator L
Indicator A		1	2	3	2	1	1	3	2	4	2	1
Indicator B	2		1	2	3	4	1	1	0	1	1	1
Indicator C	2	1		1	0	3	1	2	1	0	1	1
Indicator D	3	3	1		1	3	1	2	1	0	1	4
Indicator E	2	3	1	2		1	0	1	4	1	2	1
Indicator F	4	1	0	2	1		2	1	3	0	2	1
Indicator G	3	1	2	1	3	0		1	4	1	3	1
Indicator H	5	1	2	1	0	1	1		1	2	1	1
Indicator I	1	2	1	4	1	2	3	1		1	2	0
Indicator J	3	1	4	3	1	2	0	1	2		1	1
Indicator K	1	4	1	2	1	0	2	1	4	1		1
Indicator L	1	2	3	1	4	1	0	1	0	1	1	

Figure 4: Measurable Indicator DMM (M).

The measurable indicator DMM (*M*) was scored by the Delphi method, also known as the expert investigation method. It is essentially a feedback anonymous inquiry method. The general process is to obtain expert opinions on the problem to be predicted. Figure 4 shows the impact of sustainability of measurable indicators on the same type products in the manufacturing industry and the comparison within different measurable indicators of three different dimensions.

4 AN ILLUSTRATIVE EXAMPLE

A certain company mainly produced computer software and hardware, and entered the smartphone industry later. It implemented technology with strong innovation capabilities.

In this paper, this smart phone development project is used as an example in order to analyze the sustainability of mobile phones. The project developed six mobile phone models, labelled Product 1 to Product 6, respectively, in order to compare the mobile phones of sustainability could be put into production, saving resources and offering the highest number of benefits.

Each mobile phone was evaluated based on the materials that were used for each part, the power consumption, the impact they had on the environment, their recyclability, and other aspects. According to the sustainability evaluation model constructed in the previous chapter, the expert scored evaluation from 12 standards such as Indicator A. The scoring matrix of the six selective products (product DSM) (P) shown in Figure 5 was obtained through interviews with the project manager and other experts in the field of sustainability.

	Indicator A	Indicator B	Indicator C	Indicator D	Indicator E	Indicator F	Indicator G	Indicator H	Indicator I	Indicator J	Indicator K	Indicator L
Product 1	1	2	2	3	1	1	2	1	1	1	1	3
Product 2	1	1	2	1	1	2	4	2	4	1	2	1
Product 3	2	3	1	1	4	2	1	3	2	3	1	1
Product 4	1	1	4	2	3	2	1	1	3	2	1	1
Product 5	1	2	3	4	1	2	1	3	1	2	1	1
Product 6	1	3	4	1	4	1	5	2	1	3	1	1

Figure 5: Product DSM (*P*).

	Indicator A	Indicator B	Indicator C	Indicator D	Indicator E	Indicator F	Indicator G	Indicator H	Indicator I	Indicator J	Indicator K	Indicator L
Product 1	0.6418	0.5075	0.4627	0.4627	0.5075	0.5075	0.2687	0.3881	0.4478	0.2537	0.4030	0.4030
Product 2	0.7762	0.5522	0.4776	0.6567	0.4776	0.4478	0.4627	0.4030	0.7015	0.3284	0.5672	0.3134
Product 3	0.8955	0.5970	0.5821	0.7463	0.4925	0.5970	0.3433	0.4478	0.7015	0.4328	0.5373	0.3731
Product 4	0.7463	0.5821	0.4627	0.6567	0.3731	0.5970	0.3731	0.4478	0.6269	0.2687	0.4925	0.3731
Product 5	0.8955	0.5522	0.4925	0.5522	0.3881	0.6418	0.3433	0.4627	0.5224	0.2836	0.4328	0.4925
Product 6	1.000	0.6269	0.6716	0.7015	0.6119	0.6567	0.3433	0.5075	0.8806	0.3881	0.6567	0.4328

Figure 6: *PM* Matrix.

	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
Product 1	0.6418	0.5075	0.4627	0.4627	0.5075	0.5075
Product 2	0.7762	0.5522	0.4776	0.6567	0.4776	0.4478
Product 3	0.8955	0.5970	0.5821	0.7463	0.4925	0.5970
Product 4	0.7463	0.5821	0.4627	0.6567	0.3731	0.5970
Product 5	0.8955	0.5522	0.4925	0.5522	0.3881	0.6418
Product 6	1.000	0.6269	0.6716	0.7015	0.6119	0.6567

Figure 7: Validate Product Matrix ($T_{validate}$).

Then results of PM and $T_{validate}$ matrixes were shown in comparison (see Figure 6 and 7), both matrixes were normalized matrixes. By analyzing and comparing these two matrixes, the sustainability of these six products can be examined. However, different shareholders considered different dimensions of the measurable indicators, so it is difficult to directly determine which product to choose.

5 CONCLUSIONS

In order to explore the sustainability of products, three dimensions (economic, environmental, and social) were used in this article, giving a total of 12 measurable indicators. All of the measurable indicators were scored by experts for further exploration. The knowledge domain of product process structure is compounding sustainability indicators into its approaches. This paper introduced a five-step approach, which was split into two phases (predicting and validating). After identifying a number of products based on the measurable indicators and determining the sustainability of the selected products in the first phase, the second phase (steps 4 and 5) concentrated on validating the selected products by comparing the sustainability of the similar products. In the first phase, the two matrices (the product DSM (*P*) and the measurable indicator DMM (*M*)) were introduced to capture the measurable indicators. In the second phase, the function of the validated product matrix was defined in order to compare the level of sustainability of each of the different products. Through this process, the sustainable products were compared and even chosen for different demand.

The application of this approach was shown with the smartphone industry being used as an example. This provided relevant insights about the challenges associated with the development of new smartphones. Through the measurement of product sustainability, more environmentally friendly products will have more advantages, and consumers will favour these products more, thus counter-promoting the selection of raw materials by merchants and manufacturers and the recycling of subsequent products. The measurement of products by multiple indicators also reflects different requirements for product sustainability. Different consumers can choose products that are more suitable for them according to their own requirements, which increases the satisfaction experience for consumers.

6 LIMITATIONS AND RECOMMDATIONS

In fact, there are different categories of sustainability measurement indicators. This article only classifies 12 indicators into three categories. In the illustrative example, only six types of mobile phones were measured. Therefore, these measurement methods may not be suitable for large quantities of goods such as fast-moving goods.

Through the sustainable development of the product, the product itself can achieve continuous development in performance or function, and meet the market demand of different performance, thereby extending the service life, maximizing the recycling use of the limited resources of the brothers, and achieving the circular economy goal of utilization and recycling. Through the transformation and upgrading of modern industrial technology methods and concepts, the application of multiple life cycles and multiple performance modes of products can be realized.

For future work, we will expand more categories to consider the sustainability of products, and understand consumer needs through statistics and other methods. These measurement methods will also be applied to more fields, such as clothing. We will also optimize the model so that the measurement indicators better reflect the sustainability of the product.

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