A Framework of Integrated Sustainable Make or Buy Decision Model

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Abstract. Tolerance has been recognized as the connector between engineering design and manufacturing stages. It plays an important role in both stages and must be optimally determined to minimize several objectives such as manufacturing cost and quality loss. Considering the engineering design, the tolerance should be set tightly in order to get better quality. Conversely, considering manufacturing stage, the tolerance should be set loosely in order to make the manufacturing process less costly. Process and technological capabilities as well as limited production capacities made manufacturing companies to outsource some of their needed components to their suppliers. Hence, the manufacturing companies should decide which components have to make using its own production facilities and which one that must be purchased from the suppliers. These decisions can be made simultaneously with the determination of optimal tolerance. Due to the intense concerns on environment, sustainability gained more attention in recent years and attracted many researchers including in the field of make or buy decisions. We attempt to integrate the make or buy decisions with sustainability in the form of remanufacturing to determine the optimal component tolerance. We found that the Bass model, a widely used model to predict new product demand, can be integrated to make or buy decisions model specifically in determining the expected number of returned product to be remanufactured. We identify some problems in the integration such as the lead time which comes from the product useful life and time to collect the return product and also the representation of remanufacturing cost function in its relation with tolerance assignment, and considerations of single or multi manufacturing generations.

1. Introduction
A product goes through several stages before it is received and used by the customers. Product design and development as well as manufacturing are considered as the major stages. Product design and development consists of five phases: concept development, system-level design, detail design, testing and refinement, and production ramp-up [1]. In detail design, the designer defines the product’s part geometry, choose materials, assign tolerances, and complete industrial design control documentation. Tolerance assignment should be done carefully since it has some consequences in the downstream process. Several aspects should be considered by the designer in tolerance assignment, not only quality but also the manufacturing cost. Hence these two criteria have been used as the objective function in the basic tolerance assignment models. In order to maintain the time limitation efficiently, product design and development team should involve the manufacturing unit of the company in the tolerance assignment. The involvement will result tolerance assignment that has considered the process capability of the production facility of the company.

Some components may have tight tolerance and some other may have loose tolerance. After the assignments the company should look at their production capacity to check whether there exist some components that the tolerance so tight and cannot be achieved using the existing production facility. The
company has to decide which components must be produced in house and which ones that must be outsourced, which known as the make or buy decision problem. Some factors constrain the company in components production. At least there are three constraints in this context, namely capacity, process capability, and technological capability [2]. One of the constraints will make the company to outsource the needed components. There are two decisions in outsourcing: supplier selection and order allocation. Both decisions may be done simultaneously using an integrated decision model that has been developed by many researchers.

Sustainability has become global concern and led to a concept known as sustainable manufacturing. It aims at product creation using a process that simultaneously minimizing environmental impact, minimizing the use of energy and natural resources, and guarantee their future availability [3]. Further, according to [4], there are six key metrics in sustainable manufacturing. Three of them are easy to quantify, i.e., manufacturing cost, energy consumption, and waste management. While the rest of them, operational safety, personal health, and environmental impact, are not easy to quantify. In sustainable manufacturing, the remanufacturing and refurbishing become more important which extend the lifetime of products or product components to save the raw material resources and also preserve the environment. According to a report in [5], the remanufacturing/refurbishing of photocopiers product in three countries, i.e., Japan, Indonesia, and Singapore. Six photocopier companies are investigated and concluded the need of legislations, business model, and technologies to strengthen the remanufacturing/refurbishing activities. In Europe, they have a take back regulation to regulate the producer’s collection behaviour. The regulation in some extent gives some benefits to the stakeholders in term of manufacturer’s profit, consumer surplus, and social benefits [6].

In this research, we propose a conceptual framework to include the sustainability issue in make or buy decision making. We limit our research to specific area of make or buy decision which taking into account the tolerance assignment. The rest of this paper is organized as follows. In Section 2 we review some relevant literature. In section 3 we propose the framework. In Section 4 we provide the discussion and further research. In the last section we give the conclusions.

2. Relevant Research
Make or buy decision model has attracted many researchers. One of the early models found in literature discussing the relation between tolerance design and make or buy decision was done by [7]. They developed a model to determine simultaneously the optimal components tolerance and machine selection. This research constitutes the basic problem of in-house production. In different context, a research by [8] developed an optimization model to find simultaneously the optimal tolerance and suppliers. In real context, the decision was not only about machine or supplier selection to produce or purchase the needed components. There is another decision following the machine or supplier selection, namely production allocation or order allocation to the selected machine or supplier. With this regard, [2] and [9] solved the problem of production or order allocation and allowing more than one machines or suppliers selected. Based on those models, a model in [10] was developed to solve make or buy decision model in a multi-stage production system. Later, another model developed by [11] solved the make or buy decision problems considering the learning and forgetting model to maximize the return on investment due to the learning investment and the benefit gained from the investment in term of quality cost reduction.

Sustainability has become the concern of tolerance design and make or buy decision. For example, a research by [12] developed a model to include not only economic consideration, but also ecological cost to determine optimal tolerance allocation. They formulated the model in a bi-objective optimization. A research by [13] extended the previous model by added the quality requirement constraint and the expectation of out of specification product is derived analytically, rather than using experimental simulation. Carbon emissions have been considered as the important factor of sustainability in term of its negative impact on environment. In this regard, a research by [14] developed a model to determine the effect of carbon tax in make or buy decision. They proposed two models for both make regime and
buy regime respectively with three players including the supplier, the manufacturer, and the government. Several scenarios are developed in the research by introducing exogenous and endogenous carbon tax rate and the explore the government role in regulate the carbon tax. Following the idea of the two regimes, an optimization model was developed to include tolerance allocation in a make or buy decision system [15].

The remanufacturing of mechanical components has become the common practices in many industries. Xerox was considered as one of the earliest companies that recovered used equipment since 1960’s and formalized the remanufacturing system in 1980’s. Japan’s major original equipment manufacturers (OEMs) such as Fuji, Ricoh, and Canon started the remanufacturing in the late of 1990’s and 2000’s [5]. For more details about the company, according to McKinsey reports in 2014, Ricoh designed GreenLine brand of office copiers and printers to maximize the reusability of products and components, while minimizing the use of virgin materials. Since not all the components can be reused, Ricoh recycles and uses them in making new components which estimated will reduce about 30% of the material cost [16].

In automotive industry, China has Circular Economy Promotion Law which effectively force in 2009. Several pilot automotive remanufacturers are established since 2008. They remanufactured several automotive components such as engine, transmission, alternator, and starter [17]. Amelia [18] added some other automotive components that have been remanufactured and reused include clutches, brake shoes, water pumps, and carburetors. However, they reported that components reuse in Malaysia automotive industry is only for part replacements and not for new vehicles. In this case, the cost reduction from using the remanufactured or reused components did not justify the customers’ perception on using a car with such components. Nguyen et al. [16] reported that Renault, a French automotive manufacturer remanufactures some of their components for resale.

Although remanufacturing plays an important role in many industries, the product and component need to wait until they come in their end of life. Wang et al. ([19] and [20]) proposed the use of Bass model, a wide used model to estimate new product demand. In the research the Bass model was used to estimate the number of returned products with certain time of delay after the sale. In earlier model, they considered one product generation, while in the later research they considered multiple product generations to capture the real conditions of some products that share commonality components within different product generations. The time delay in this context consists of product’s usage time and the reverse logistics handling time.

3. The Proposed Framework
The proposed framework of this research is shown in Figure 1. The figure shows the product life cycle from product design until disposal. In product design stage, the company define the part geometry, appropriate materials, dimension, and assign component tolerance involving the manufacturing division of the company. Before move to manufacturing stage, the company should determine which components should be made in-house and which ones that must be purchased from the suppliers. Three constraints involve in the make or buy decision, namely production capacity, process capability, and technological capability. After manufacturing and assembling process, the product entering the market and bought by customers with certain price and it starts its useful life. After some time, which may take several months or years, the product arrives at its end of life. The product is then sold by the customer to a collector which will disassemble the product and conducting a screening to assess the condition of the components. If the condition is good, then it will be remanufactured, reused, or recycled by a certain company. If the condition of the components is not good, then it will be disposed with a certain cost.

The make or buy decision in this framework has close relation with tolerance assignment. Tighter tolerance results in better quality components or products which means lower quality cost, but higher manufacturing cost. While looser tolerance results in higher quality cost and lower manufacturing cost. There are three quality costs included in this issue: prevention, appraisal, and failure costs. Prevention
cost deals with any activities to prevent the quality problems such as new product review, quality planning, quality education, and training. Appraisal cost includes inspection, product and process audits, and calibration. Failure cost consists of internal and external failure costs. Internal failure cost occurs prior to delivery or shipment of the product which includes scrap and rework costs. External failure cost occurs after the delivery or shipment such as customer returns, warranty claims, and product recall.

The make or buy decision may be made in both product design and manufacturing stage. In an engineered to order company, the make or buy decision is not only in manufacturing stage but also in product engineering design stage ([21] and [22]). The general structure of make or buy decision is depicted in Figure 2. The figure shows that there are two alternatives in providing design and components, through in-house production and outsourcing. The components production needs inspections to ensure the quality. Finally, the components will be assembled in the manufacturer side and delivered to the customers.

4. Discussions and Further Research

In real world, a product should go through its useful life before arrives at its end of life and collected for remanufacturing process. Many remanufacturing researches did not consider this condition as the lead time. Usually only time to collect the return product and its transportation which considered in the research. One of the researches that considered useful life as the lead time was done by Wang et al. ([19]
and [20]). They used Bass model, a well-known model to estimate the demand of new product or technology based on imitation and adoption of customers on a product, to estimate the number of return product. In the former research they developed a model to estimate the number of return product considering the market diffusion using Bass model with one generation, while in the latter the multiple generations model was developed. The multiple generations model quantify potential component reuse volume considering time delay, market saturation, loss in reverse logistics and reprocessing operations as well as component obsolescence.

In relation with product quality, the returned product needs a certain treatment in remanufacturing process so as to be ready to be reused. There are several characteristics which determined the quality of a returned product. In mechanical assembly, one of the important characteristics is the critical dimensions of a product or component. The critical dimensions will determine the quality level of the returned product or component and the level of remanufacturing process to restore their functions. Hence, it is imperative to determine or formulate a function to define the relationships between the cost of remanufacturing, level of quality, and level of remanufacturing process. The returned product should be inspected to determine the level of quality and the manufacturer will decide the level of remanufacturing process based on the level of quality. Those activities need certain costs both fixed and variable costs. The results of remanufacturing process will result different impact on the costs in term of quality loss of the product.

A mathematical model needs to develop in order to solve the problems. First, a make or buy decision should be done simultaneously with the order allocations. Buy decisions involve multicriteria decision making in supplier selection. Many multicriteria decision making methods have been used to solve this problem such as AHP, ANP, TOPSIS, and the hybrid methods. Afterwards, another model should be developed to determine the proportion or number of returned product which must be remanufactured and fed into the manufacturer. The remanufactured products are then assembled with other components to results the final products.

5. Conclusions

In this research, an integrated framework was developed to determine the optimal decisions concerning make or buy decisions. The decisions were affected by several aspects of production such as production capacity, technology, and process capability. Hence, tolerance has an important role in such decisions. The framework involved sustainability in term of product remanufacturing. The returned product can be determined using the Bass model which widely used to estimate the market volume of new product. An important function to relate the cost of remanufacturing, level of quality, and level of remanufacturing process should be developed in the integration. For further research, we will develop those models as the implementation of the framework.

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