Constructing indicators for quality assessment on sorting of used products in remanufacturing system

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**Abstract.** Recently, a considerable literature has grown up around the theme of remanufacturing. In the past decade has seen the rapid of remanufacturing practices in many heavy equipment companies.A key aspect of remanufacturing is core acquisition management, one of which is the main problem is the uncertainty of the quality of incoming cores.Sorting and quality classification plays an important role in the operational level of remanufacturing systems to handle the variability condition of incoming cores. The purpose of this study is to extend an existing approach to classify/sort the incoming core quality into predefined classes by using quality indicators in decision making. Firstly, the set of criteria for quality of the used product were presented. Secondly, the index system was proposed to determine the level of criteria for quality assessment of incoming core.Overall, eleven indicators were proposed based on technological, physical and usage conditions to assess quality of incoming core for case study in a heavy equipment remanufacturing company.

**Keywords:** core acquisition, quality uncertainty, grading, multi-criteria, decision making

1. Introduction

An increasing number of heavy equipment demand in Indonesia has been demonstrated by Simatupang [1]. However, it has been found that the supply of new equipment was far from adequate, due to the limited capacity of local heavy equipment manufacturers, import regulations for special heavy equipment are complicated, and procurement time for ordering equipment is quite long. In particular, Simatupang [2] emphasized that the availability of heavy equipment for construction cases in Indonesia is only 20% of total demand. It can be seen from figure 1 that there was a significant gap between demand and availability of heavy equipment. There remains a need for an efficient method that can fulfill the gap between supply and demand for heavy equipment. One way to overcome this gap is to recover the old (used) heavy equipment by using a remanufacturing strategy. Recently, heavy equipment companies in Indonesia have shown an increased interest in remanufacturing, for example, many of them are members of the Heavy Equipment Manufacturers Association of Indonesia (HINABI) [3].

Remanufacturing is an industrial process which is not only using technical manners to restores the worn-out product (core) to at least the same performance as good as new product working condition, but also considering economic and environmental aspects [4]. Remanufacturing can play an important role in addressing the issue of sustainable manufacturing to value retention for a worn-out product, which has widespread attention around the world. Remanufacturing has paid attention extensively due to its possible benefits and potential applications. For example, the cost savings (up to 50%) due to the reduction in energy consumption (up to 60%) and material usage cost (up to 70%) are the economic benefits that could be generated from remanufacturing practice [5]. These costs are much less than in manufacturing, so that allow remanufacturer to offer remanufactured products at market prices around 50-80% cheaper than new products with a profit margin of around 20% [6,7]. Furthermore, remanufacturing able to reduce environmental impacts, by reducing carbon emission during processes and minimizing waste output. Moreover, labor-intensive of remanufacturing operations (such as grading, sorting, disassembly, and reassembly) has a social benefit to create new jobs. Therefore, remanufacturing can also be seen as a win-win solution; saving the money (for remanufacturers and customers), protecting the environment, and improving social welfare.

Remanufacturing has many potential economic and environmental benefits over conventional (forward) manufacturing, on the other hand remanufacturing practice involves a complex system that includes many activities such as core acquisition, a series of operations: inspection, sorting, cleaning, testing, disassembly, reconditioning, reassembly, and remarketing. In remanufacturing, the quality condition of cores can vary significantly, affecting remanufacturing operations and cost of remanufacturing. One of the greatest challenges is the process of managing returned products of remanufacturing under complexity and uncertainties in volume, time, and quality conditions [8,9]. The term quality condition has been used to refer to the characteristics of the used products in which such as the effect of the remaining the life cycle of the parts/products. It can be measured by two characteristics, namely physical condition and technological obsolescence [10]. One of the main obstacles in the core acquisition is how to manage the quality uncertainty condition of the incoming core. As the quality of the incoming cores are not known beforehand, the quality level of cores are subject to uncertainty. The term uncertainty was used to refer to situations in the lack or incompleteness of information. In theory, this is also called epistemological uncertainty which is often referred to as confusion, subjective uncertainty, knowledge-based uncertainty, and phenomenological uncertainty, as well as reducible uncertainty [11]. Even though it was difficult to handle the quality uncertainty in remanufacturing system, a quality control framework have been proposed by Mustajib et al. [12]. In their study, suggested a possible quality control to reduce the uncertainty of core variability by dividing into three levels of the area; strategic, tactical, and operational. At an operational level, core variability is graded by sorting and classifying manually which can be time-consumingand depends on the labour skills and knowledge, whereas fast sorting can be realized by installing an information and communication technology application.

Sorting and quality classification are important components in quality control and play a key role in the operational level of remanufacturing systems to handle the variability of the incoming core. In the literature of decision science [13,14], the term classification has come to be used to refer to the assignment of a finite set of alternatives into predefined clusters or classes (see figure 1). On the other hand, sorting refers to problems where the groups are defined in an ordinal way. These definition have been widely used by multi-criteria decision aiding (MCDA) researchers. The decision making of sorting and quality classification is technically challenging, as any classification process covers a high degree of uncertainty implicit in the quantified information. According to Golinska et al. [15] this is occurred because of an approximation when using the experts' knowledge.

In recent years, there has been an increasing interest study on sorting and quality grading for evaluating the quality of used products. It is only since the work of Guide and Wassenhove [16] that the study of sorting and grading of used mobile phones quality has gained momentum. Five years later, Seliger et al. [17] reported a case of quality classification for Liquid Crystal Display (LCD) monitor components based on visual, mechanical, electrical, audio, display, and logical testing. In their major study, Behdad and Thurston [18] have proposed an analytical approach to evaluate the process of upgrading used house-hold electric appliances which are graded into different quality levels. A quality evaluation model based on the fuzzy analytic hierarchy process (AHP) to evaluate the reusability degree of the end-of-life wheel loader was presented by Zhou et al. [19] . Their model and its management system are useful to increase the efficiency of workflow. Meanwhile, to determine the best upgrade level for a received product with a certain quality grade level, Mashhadi et al. [20] developed a stochastic optimization model based on chance-constrained programming. In another major study, Mashhadi & Behdad [21] have proposed a new sorting method based on both of product’s internal and external factors to better decision making in remanufacturing. This data-driven method was provided by an application of sensor data. In two related analyses are carried, first, they proposed a reusability index of used products, second, they built a clustering algorithm to identify similar characteristics of products based on the index.

As noted by Xin [22] the condition of the used product have a different degree of uncertainty has made the evaluation process is more complicated, therefore need index evaluation model more scientific to improve the decision-making process. It is necessary to provide an index system to address the variability quality condition of incoming cores. To do this, the aim of this study was to presents a set of criteria and index systems forsorting the incoming core into predefined classes to handle quality uncertainty. Although in many ways similar, the proposed criteria and the index are significantly different from Xin [22].

Furthermore, this paper is organized as follows. First of all, section 1 introduces the backgrounds and problems, literature reviews, and limitations of previous works. Second, in section 2 we provide descriptions about our proposed methodology for sorting problems in incoming core quality classification. Section 3 focuses on results and discussion based on a case study presented of heavy equipment part remanufacturing to show the application for quality classification. Finally, we conclude with some summary.

1. Methods and Materials

There are many methodologies available that have been developed from a wide range of research disciplines for addressing the classification and sorting problems. Several methods currently exist for the investigation of uncertain systems: fuzzy mathematics, grey system theory, probability, and statistics. In a grey clustering model acts as a system that transforms an input into an output. The input contains an object and quality index system, while the output is the quality class of the incoming cores. Generally speaking, the quality class is a collection of information on the qualitative properties of the evaluated object, which enables the identification of the criteria and the identification of the results obtained [23].

The first step in this sorting process was to determine the criteria for classifying the incoming core. Once the criteria $\left(1,\cdots j,\cdots J\right)$ were available, the sub criteria and its index system to measure the quality level can be defined. After that, setting for the incoming core into object of$\left(1,\cdots i,\cdots I\right)$ and the quality classes were divided into$ \left(1,\cdots k,\cdots K\right). $When dividing quality classes, care was taken to the evaluation requirements. Following this step, the data form was transferred according to the different indexes polarity. Prior to determining the clustering weight $η\_{j}\left(1,\cdots j,\cdots J\right)$ of each index, the indexes were whitened using possibility functions for whitenization. A value of $η\_{j}$ that closer 1 means that the most important. After being whitened, the grey fixed weight clustering coefficient was calculated. Moreover, calculate the clustering weight vector according to the fixed weight coefficient of each class, and then find the clustering coefficient matrix. After the matrix was found, the class that certain object belongs to according to the clustering coefficient matrix can be determined. The final step of grey clustering model is to determine the priority orders of objects based on the class and value of clustering coefficient.

1. Results and Discussion

The eight dimensions of quality for new products have been proposed by Garvin (1987). Unfortunately, these dimensions do not always can be recognized on used products. There remains need for compatible quality criteria with used products. In order to provide the quality criteria for used product, Mustajib et al. [26] have established that the quality criteria for sorting the incoming core based on: technological, physical, and usage conditions.Let us consider, there were eight $\left(I=8\right)$ incoming core of used hydraulic cylinder of heavy equipments which were acquired by the remanufacturer, and they needed to be classified based on these criteria which are then expanded into 11 sub-criteria $\left(J=11\right).$ Moreover, the hydraulic cylinder are sorted out into three distinctive grey classes$\left(K=3\right)$, namely: bad, middle, and best. The classification for the *ith* core into the *kth* grey class based on the observed value of the *ith* core judged against the *jth* criterion is indexed by *xij*

Assessment indicators are used to measure the quality condition level of a core. In order to evaluate these indicators, we need to establish an evaluation index system used to control and measure uniformity.The index developed in these indicators are presented in Table 1 of appendix. But, due to the high uncertainty in the core conditions, sometimes it is very hard to determine the technical index quantitatively for each criterion as its complexity and the difficulty; thus, it can only be measured qualitatively by expert assessment as can be seen in the table 1. Overall, this research was conducted with the aim of assessing the importance of the quality level in used products. The most interesting finding was that the assessment formula can be obtained quantitatively and qualitatively of indicators.

1. Conclusion

The purpose of the current study was to extend an existing approach to classify/sort the incoming core quality into predefined classes by using grey decision making. The results of this study show that grey clustering is a powerful method which is concerned to classify observation index or observation objects into definable groups. An implication of this is that quality criteria for sorting the incoming core based on: technological, physical, and usage conditions. This study provides a comprehensive quality assessment of incoming core in the core acquisition of the remanufacturing system. Overall, eleven metrics were suggested, focused on technical, physical and use conditions.

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**Appendix**

**Table 1.** Criteria for assessing the quality level of incoming cores

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sub-Criteria(Assessment indicator) | Description | Assessment Formula (index) | Value range | Reference | Targetvalue |
| Technological conditions: |
| A1: Obsolescence | The condition in which the technology of used product has shown its out of date, as the product's life cycle was longer than the design life and the emergence of new technological innovations | Expert’s questionnaire, or | 1-5(scale) | 5 | Max |
| A2: Upgradability | The ability of a used product when in the remanufacturing process is easier to upgrade for functional or feature enrichment process so that the product is easier to adapt to new technology to avoid obsolescence | Expert’s questionnaire, or | 1-5(scale) | 5 | Max |
| A3: Multi-lifecycle | The condition of the used product life cycle that can be recovered for its useful life | Expert’s questionnaire | 1-5(scale) | 5 | Max |
| A4: Disassembly capability | The ability of the product or core to be easier for dismantling | Expert’s questionnaire | 1-5(scale) | 5 | Max |
| Physical conditions: |
| B1: Damage level | Indicating a grade of physical defect or damage. For example cracks, corrosion, wear | $$\frac{Number ofdamages}{Total number of allowable damages}×100\%$$ | 0-100(%) | 0% | Min |
| B2: Components completeness | The level of completeness of the components as a whole system of used products | $$\frac{Number ofavailable components}{Total number of components}×100\%$$ | 0-100(%) | 0% | Max |
| B3: Traceability of identity | Easiness of tracing for the product variation information of the model or type. For example the manufacturer's number as an identification number. | Expert’s questionnaire | 1-5(scale) | 5 | Max |
| B4: Dimensional tolerance | The allowable dimensional or geometrical variation limit at the core | $$\frac{Amount of variation}{Amount of variation limit}×100\%$$ | 0-100(%) | 0% | Min |
| Usage conditions: |
| C1: Frequency of uses | The frequency of using the product during the usage phase | $$\frac{Number of executed uses in period t}{Total number of planned uses in periode t}×100\%$$ | 0-100(%) | 0% | Min |
| C2: Maintenance frequency | The intensity of product maintenance is carried out during the use phase | $$\frac{Number of executed maintenance in period t}{Total number of planned maintenance in periode t}×100\%$$ | 0-100(%) | 100% | Max |
| C3:Remaining useful of life | The remaining usable time for a specified period.  | Expert’s questionnaire, or$$RUL = mean useful life\left(T\_{m}\right)-actual useful life of parts$$ | 1-5(scale) | 5 | Max |