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DECISION-MAKING UNDER UNCERTAINTLY IN REMANUFACTURING PROCESSES: AN EXPLORATORY STUDY

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Abstract

Most decisions in remanufacturing focus on a specific sub-system within the production process and neglect how the decision interacts with other decisions. This study aims to investigate decision-making within remanufacturing. The research identifies specific decisions found in remanufacturing processes and analyses their interplays with other decisions. Quite often, one decision will affect other decisions and the result is that the remanufacturing process becomes more complicated. This is not only because there are many uncertainties in remanufacturing, but also because of the effects of interactions. In particular, this research examines how a company deals with uncertainties in decision-making during the remanufacturing processes. A GRAI grid is used to map the positions of various decisions made throughout the remanufacturing process. This is used as it displays the overall remanufacturing process in a graph, so that interplays between decisions can be seen more clearly. The use of GRAI grid to present interplays between the decisions is remanufacturing is the novelty of this study. It is the first time the grid was utilised in the area of decision making remanufacturing context. The methods utilised by remanufacturing companies to overcome the complexities of decision-making are also discussed. Lastly, directions for future research are presented.

Keywords: decision-making, remanufacturing, GRAI grid, case study research, sustainability

Abstrak

Mayoritas penelitian dalam bidang remanufacturing menginvestigasi bagaimana keputusan diambil dalam suatu sub-sistem yang spesifik. Penelitian ini berupaya untuk menginvestigasi bagaimana pengambilan keputusan dalam bidang remanufaktur dengan secara integratif. Beberapa subsistem dalam remanufaktur akan dijadikan obyek investigasi secara sekaligus dalam penelitian ini. Pengamatan seperti ini diperlukan mengingat pengambilan suatu keputusan seringkali berpengaruh terhadap keputusan yang lain sehingga proses pengambilan keputusan menjadi lebih kompleks. Terjadinya kompleksitas ini disebabkan tidak hanya karena adanya unsur ketidakpastian dalam proses remanufaktur, tetapi juga karena adanya interaksi diantara keputusan-keputusan tersebut. Secara lebih spesifik, penelitian ini mengamati bagaimana perusahaan remanufaktur mengelola ketidakpastian dalam pengambilan keputusan dalam proses remanufaktur. Metode GRAI grid digunakan untuk memetakan secara grafis bagaimana berbagai pengambilan keputusan dalam berbagai tahapan proses remanufaktur. Dengan metode seperti ini, maka interaksi berbagai keputusan dalam proses remanufaktur dapat diamati. Metode yang digunakan oleh perusahaan remanufaktur untuk mengatasi ketidakpastian juga didiskusikan dalam artikel ini. Di bagian akhir, disajikan rekomendasi untuk melakukan penelitian lanjutan.

Kata kunci: *decision-making, remanufacturing, GRAI grid, case study research, sustainability*

INTRODUCTION

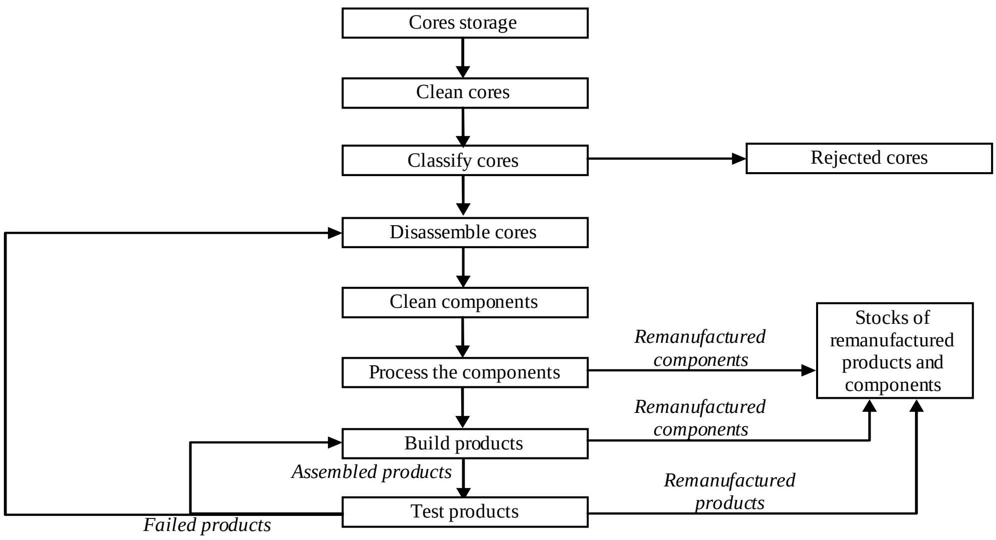
The origin of product recovery can be traced back to 1984, when Lund (1984) investigated the practice of remanufacturing in the US and several developing countries. Since its initial emergence in 1984 until the present time, an abundant number of studieshave been carried out to investigate related practices.

It was not until the early 1990s that the number of publications grew rapidly, but academics began to step back by questioning whether remanufacturing was a profitable business (Guide & Van Wassenhove 2009). Unlike the earliest adopters of recovery activities, which were purely profit seeking, the motives of manufacturers that adopt product recovery activities in the early 1990s were far more complicated to identify. This is because other triggers appeared, such as governmental pressure, customer preferences and competitor pressures. In fact, during that time, many companies did not pay attention to pressures from both government and competitors only a small number of companies paid attention to these issues.

The pattern of adoption of product recovery activities has been different forAmerican and European companies. European companies adopted the practice due to regulatory pressure. The introduction of Waste Electrical and Electronic Equipment (WEEE) directives not only triggered companies in the region to adopt relevant practices, but also prompted academics interested in the topic to develop research groups. Thus, it is not surprising to find research groups such as RevLog, or whole departments, devoted to examining product recovery, such as one at Erasmus University, in Amsterdam. On the other hand, American companies adopt these practices in response to market pressures. Companies adopting environmentally-friendly practices have provoked their counterparts to implement similar activities (Luyima et al. 2012).

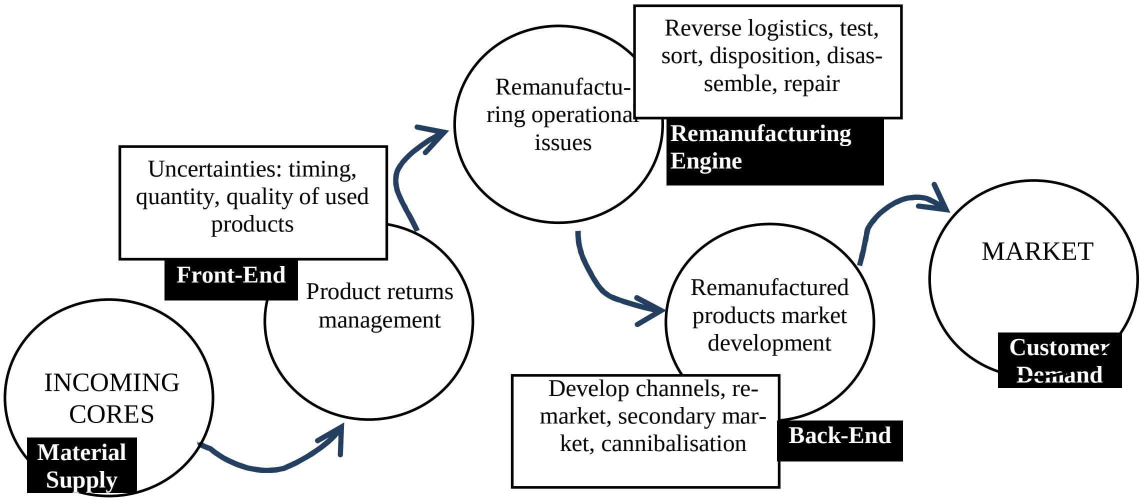
A rough examination of the location of recent and current research studies indicates that the number of studies conducted in African, Asian and Middle-Easternregions are scarce in comparison to the US and Europe. However, this does not mean that those regions are late adopters of product recovery initiatives. Indeed, Nigeria, Bolivia, Chile, India and Pakistan are among early pioneers of such activity, where labour availability, local talent and relatively low labour costs strongly support product recovery projects (Lund 1984).

In the early introduction of product recovery, remanufacturing was the most commonlyused methodology, with discussion focused on technical and operational problems. Just a few years after Lund's early study, research mostly discussed how to overcome technical problems during the recovery process. Remanufacturing is defined as the process of returning a used product to at least its original equipment performance specification, from a customer's perspective, and providing a warranty for the resultant product that is equal to that of its newly manufactured equivalent (Ijomah & Chiodo 2010). The generic process of remanufacturing is presented in Figure 1. As can be seen in Figure 1, some of the processes are iterative in nature.For example, assembled products can be disassembled again, and the components are retested to ensure the final products meet the required specifications.



Adapted from Ijomah et al. (2007)

Figure 1 Process of remanufacturing



Source: adapted from Guide et al. (2009).

Figure 2 Evolution of research into product recovery

The topics of research into remanufacturing have shifted over the three decades that the area has been the subject of academic attention. How these topics have evolved is presented in Figure 2. As displayed on left-hand side of Figure 1 – pertaining to the Front-End – the main problem throughout the remanufacturing processesis uncertainty in terms of time, quantity and quality of the cores that arrive with remanufacturers. Remanufacturers do not have access to information regarding *when* the cores will arrive (time), in *whatcondition* they will be in (quality) and *how many* (quantity) they will receive. Once the cores have arrived at the remanufacturing sites, uncertainties related to *when* and *howmany*will beovercome.

Nevertheless, uncertainties are still present, as the quality of components that make up the products has not yet been determined. Poor management of these uncertainties will havea negative effect on the effectiveness of operational practices and consequently reduce the value delivered to customers. In Figure 2, these activities are categorised as‘Front-End’elements of the remanufacturing processes. Activities conducted to investigate these uncertainties include sorting and assessing cores (Zikopoulos & Tagaras 2008; Galbreth & Blackburn 2006), lot sizing (Konstantaras et al. 2010; Schulz & Ferretti 2011), and supplier selection (Ferrer 2003). This area is relatively new to scholars,as it only began to gain greaterattention inearly2010.

Compared to Front-End processes, the Remanufacturing Engine – in the middle of Figure 2 – has received a considerable amount of scholarly attention. These works mostly address technical and operational issues with remanufacturing, using a quantitative method and operations research. These studies, according to Guide and Van Wassenhove(2009), are located in the ‘safety area’, where authors utilise mathematical modelling without the support of empirical data. Further, Guide and Van Wassenhove(2009) labelthe period spanning fromthe 1990s to the early 2000s as the ’golden age“. In this period, studies focused on shop-floor activities with a view to minimising cost byimproving profitability or reducing the cost of operations. Some examples of these activities include inventory management (Guide Jr. & Srivastava 1998; Piplani & Fu 2005), inventory control(Hsueh 2011; van der Laan et al. 1999; Nenes et al. 2010), lot sizing (Konstantaras et al. 2010; Ahn et al. 2011; Li et al. 2013), material planning (Ferrer & Whybark 2001; Johnson & Wang 1995), and product acquisition (Galbreth & Blackburn 2006). An excellent discussion of the methods used to analyse these technical and operational activities can be found in Rubio (2008). In Figure 1, these activities are categorised as relating to theRemanufacturing Engine.

After the remanufacturing processes are complete, the next stage is the Back-End processes. In this phase, similar problems occur from the demand side regarding *when* the customers will request remanufactured products, and in *what* quantity. The degree of acceptance of remanufactured products remains unclear, as early studies have presented conflicting empirical findings (Guide &Li 2010; Atasuet al. 2010) , highlighted by studies in recent years. There are many research gaps in this area, particularly regarding marketing issues and customer acceptance of remanufactured products.

In addition to the literature gapsdiscussed in the previous paragraph, existing studies tend to utilisea single discipline - particularly production and manufacturing - and lack a commercial perspective. As business organisations, remanufacturers should also take into account other business processes, such as finance, marketing, purchasing and distribution. This idea has been discussed by Guide and Van Wassenhove(2009), who point out that there is a need to examine product recovery processes using various perspectives to ensure a more comprehensive understanding. In other words, research is required that connects related functions within a company who make decisions in the three areas presented in Figure 2 above – Front-End, Remanufacturing Engine and Back-End – as a comprehensive business model(Guide & Van Wassenhove 2009).All these decisions have to be made in relation to the remanufacturing processes as an integrated system. Additionally, each processmust be interconnected,because addressing each uncertainty as an independent subject ignores the fact that there are complex interactions between components within the remanufacturing systems.

RESEARCH QUESTIONS

Each phase in the remanufacturing process is related to theothers, and a decision made in that phase affects other decisions. In order for the remanufacturing process to be efficient and effective, these decisions must be synchronisedthroughout the entire system(Guide Jr. et al. 1999). This condition makes the decision-making process complicated, as there are more uncertainties involved in theremanufacturing process than in conventional manufacturing. Some differences between remanufacturing and conventional manufacturing have been identified in previous studies (Guide Jr et al. 2000; Guide Jr. et al. 1999).

Several attempts have been made to synchronise the sorting and disassembly processes. Zikopoulos and Tagaras(2008) analyse the value of sorting in the disassembly process,while Johnson and Wang (1998)advocate integrating the disassembly process with economic valuation. However, these studies primarily focus on the effect of one decision on another without anyattempt to integrate other decisions from relevant sub-systems in the remanufacturing processes. For example, a study ofthe effect that disassembly decisions have on other decisions, such as material requirement planning, insertion of new cores and reassembly decisionshas never been conducted, yet interactions among these decisions make the remanufacturing process more complicated.

In addition to theresearch gapshighlighted above, the decision-making actor is also missing fromexisting investigations,though decisions can affect different parties within the company. For instance, the decision to disassemble not only affects material requirement planning, but also purchasing, disassembly process and final product cost. Consequently, the disassembly process has an indirect effect not only on material planning but also on the pricing strategy forthe remanufactured products. In summary, the major research gaps and areas requiring academic attention include the following:

- *Lack of integration between different functions within the company*. Decisions have to be made by people from within different functionsof a company. For example, the decision to disassemble has to considerbothtechnical aspects - which is a concern of shop floor workers - and economics aspects. Hence, a decision of this type must be made collaboratively, involving people from different functions.
- *Need for a system-based approach, as opposed to sub-system based.*An argument for this is put forth by Guide *et al.*(1997), whoexplain that remanufacturing constitute of sub-systems that are interconnected each other. Accordingly, investigating the system as a whole is more relevant than investigating each sub-system as an independent entity. Examining uncertainties with an integrated view of the system as a whole

will provide significant value to bothaca-demics and practitioners.

- *Decision-makers in remanufacturing processes have been neglected by existing investigations.*Decision-making within re-manufacturing systems is not directly com-parable to that within manufacturing sys-tems(Guide Jr. et al. 1999), as remanufac-turing is characterised by greater uncertain-ty, which makes the decision-making process more complex. Who makes the de-cisions and how conflicting interestsof dif-ferent parties are managed within these companiesare under researched.

The above research gaps imply particular re-search questions, which are explained below: 1) There are many decisions that need to be made in remanufacturing operations that are not found in manufacturing systems. These are a source of uncertainty that potentially create bottlenecks. Hence, risk in remanufacturing systems is higher compared with conventional manufacturing. To overcome these uncertain-ties, identification and mapping of current deci-sions is necessary. To this end, a suitable re-search question is: *What unique decisions are found in the remanufacturing process and how do these decisions interplay with others?* 2) The remanufacturing process is a complex sys-tem, where one decision affects the others. For example, the disassembly decision affects MRP and re-assembly decisions. As each decision may involve particular uncertainties, these will influence the uncertainties of other decisions. Also, from the decision-makers' point of view, there is a chance that a decision mightconflict with another decision. Thus, a possible line of enquiry identified here is*: How do decision-makers make these decisions?*

RESEARCH DESIGN

The purpose of designing research is to ensure that the data collected ispertinent to the re-search questions stated at the outset (Yin 2009). Due to the relatively new and complex charac-teristics of the research questions, this study utilises a case study method. The case study method is appropriate for an exploratory study, as it enables researchers to identify not only causal relationships, but also answer *what*, *why* and *how*(Yin 2009; Eisenhardt 1989). It allows for a deep and comprehensive investigation particularly for unique case which is extremely rarely to occur (Siggelkow 2007). The method is powerful approach to develop a theory in operations management (Meredith 1998) that works well with a wide range of research para-digm (Meredith et al. 1989). In the field of op-erations management, qualitative approach with case study method is predicted to be more pre-valent in future years (Craighead & Meredith 2008) so that the use of the method in this study is in line with the trend.

The case company

To investigate the proposed research questions, acase study of a multinational heavy equipment remanufacturing company located in Borneo is used.The company is a joint venture between Indonesian and Japanese companies. As of 2013, it has successfully remanufactured 8,419 products for roughly 20 companies. Although the company's main business is as an OEM remanufacturer, it also acts as a third party re-manufacturing provider for other OEMs.

A single case study design was chosen for several reasons. This design is preferable when multiple cases cannot achieve the pur-pose of the study properly. This happens in stu-dies investigating rare phenomena, unique cas-es and revelatory cases where the use of mul-tiple cases is almost impossible (Yin 2009).

Case study design

This study uses a single company as the subject for a number of reasons. As pointed out by Wilson and Vlosky (1997), the selection of a subject as a sample is determined basedon its potential contribution to theoretical and know-ledge development. Random sampling methods that theoretically generate higher generalisa-tions are not relevant for this research, due to the uniqueness of the research questions being investigated. In addition to these rationales, the case in this study was not selected on criteria such as those used for hypothesis testing, but rather for the theoretical insight that the par-tiular company can offer (Eisenhardt & Graebner 2007).

Unit of analysis

Yin (2009)defines the unit of analysis as the main entity that constitutes the focus of investigation. In this study, the unit of analysis is a decision. Decision in this study refers to a specific type of decision found in the remanufacturing context only. Decisions that are similar to those made in conventional manufacturing systems are excluded from analysis.

Data collection techniques

Data was collected using interviews, observation and company visits. The data was gathered from four different sources: employees, supervisors, shop floor managers and production managers, as they are responsible for managing production planning, forecasting and controlling remanufacturing operations. For this reason, they are the best source of data pertaining to the research questions addressed in this study. Follow up communication via e-mail and telephone was used in the case of data that required further clarification. Triangulation was performed by comparing the different informants – i.e. employees, managers and supervisors –anddifferent types of data - e.g. paper documents, electronic documents, interview transcripts and direct observations.

FINDINGS AND ANALYSIS

The analysis of the empirical findings of this study will be organised into two sections, based on the research questions proposed at the outset. The first research question deals with the identification of and interplays between unique decisions in remanufacturing, whereas the second relates to decision-making method in a remanufacturing context.

RQ1. Unique decisions in the remanufacturing process and the interplays between different decisions

To address the first research question, a literature review in the area of manufacturing strategy, production planning and control and supply chain management was conducted, to identify specific decisions also found in a remanufacturing context. Datacollected in interviews with managers in case companies will be used to inform an understanding of how these decisions are made. Studies by Ijomah(2009), Guide Jr et al. (2000) and Guide Jr. (2000)are used initially to identify specific decisions found in remanufacturing processes. Iterative processes between data analysis and data collection are continuously conducted to identify unique decisions in remanufacturing.

According to the results of the literature review and data analysis, a number of unique decisions found in remanufacturing are presented in a ‘Graphs with Results and Actions Inter-related Grid’ (GRAI Grid), which can be seen in Figure 3. The decisions are mapped in the grid and the data collected from companies is presented in the figure. The figure also shows how the decisions interact – i.e. how one decision affects the others. All of the decisions are unique and found in remanufacturing process only.

The GRAI Grid was selected as it has been popular in manufacturing research for integrating business (Wen et al. 2007). With the assistance of visual representation from the-GRAI grid, interactions between decisions can be analysed. Furthermore, the grid also assists with identifying which decisionsare most influential over others. The importance of the decisions is indicated by the number of arrows coming into and out of the decisions. A higher number of arrows coming into a decision indicates that it is affected by many other decisions;the higher the number of arrows coming out a decision, the more it affects other decisions. The details of the decisions and how they affect others are listed in Table 1 below, where the numbers in parentheses indicates the code for decisions shown in Figure 3.

RQ 2. Strategy for dealing with the unique decision in remanufacturing

To answer the second research question, the unique decisions identified in response to the first research question and presented in the GRAI Grid were scrutinised. Each decision was analysed with the purpose of identifying certain patterns across different decisions. The analysis shows that every decision in the remanufacturing process interacts with decisions in other processes. Quite often, a decision creates uncertainties in other stages of remanufacturing, and sometimes a decision cannot be made before a decision regarding a preceding process has been made.

From the case company, this study identified two main sources of uncertainties in decision-making: internal and external. Uncertainties arising externally include variations emerging from outside the organisations, including the timing, quantity and quality of the returned products. On the other hand, internal uncertainties include variations in remanufacturing processes, such as the quality of the products, the remanufacturing lead time, the yield rate of the process and the probability of the station experiencing failure. The result of these uncertainties can be either oversupply or undersupply of cores as the raw material for remanufacturing, obsolescence in inventory and inefficient remanufacturing operations. This finding confirms the work of Aksoy and Gupta (2005).

To cope with uncertain decisions in remanufacturing, the case company employs several methods, which can be broadly categorised into three groups. First, the case company uses information and communication technologies to support collaboration with customers, suppliers and third party service providers – for example, vendors that provide services for cleaning components. It also uses technology to conduct joint forecasting and to communicate regarding the product delivery schedule and product history during its use. Throughthis use of technology, many activities can be carried out more efficiently, because the condition of cores can be determined in advance before they arrive at the company's facility.

Table 1: List of unique decisions in remanufacturing and their interplay with others

No.	Decisions	Affected decisions	Rationales
1.	(1) To accept or reject cores	(2) To disassemble	The number of accepted and rejected cores determines how many cores will be disassembled and, accordingly, this affects the number of available disassembled components
		(5) To reject or dispose parts	The tighter the criteria for accepting cores, the higher the number of low quality cores that are rejected. Low quality cores tend to have a higher number of rejected components once they have been disassembled. Thus, the decision to accept or reject cores affects the number of disposed components.
2.	(2) To disassemble	(3) To sort and classify parts	Decisions to disassemble affect the number of parts requiring sorting and classifying, and therefore these decisions affect capacity planning for the sorting workstation. The number of people and resources in the station should be adjusted according to the number of cores that are disassembled at the disassembly workstation.
3.	(3) To sort and classify parts	(4) To stockparts	The sorting and classification process identifieswhich components are eligible for further processing, and which are not. The eligible components are assembled as required, while the rest are stored in warehouses as stock.
		(6) To assemble	The higher the number of disassembled components that are available in the warehouse, the better chance the company has to be successful in the assembly process. Quite often, the case company cannot assemble components due to a limited number of components available in the warehouse.
		(5) To reject and dispose of parts	Part sorting and classification determines how many parts will be disposed. If employees responsible for sorting apply tight criteria for sorting, this will reduce the number of disposed parts.
4.	(5) To reject and dispose of parts	(4) To stock parts	Decisions to reject and dispose of parts influence the number of stock parts. When the case company attempts to increase the standard for rejecting parts, the number of accepted cores will decrease, which will eventually increase the amount of stock in the warehouse.

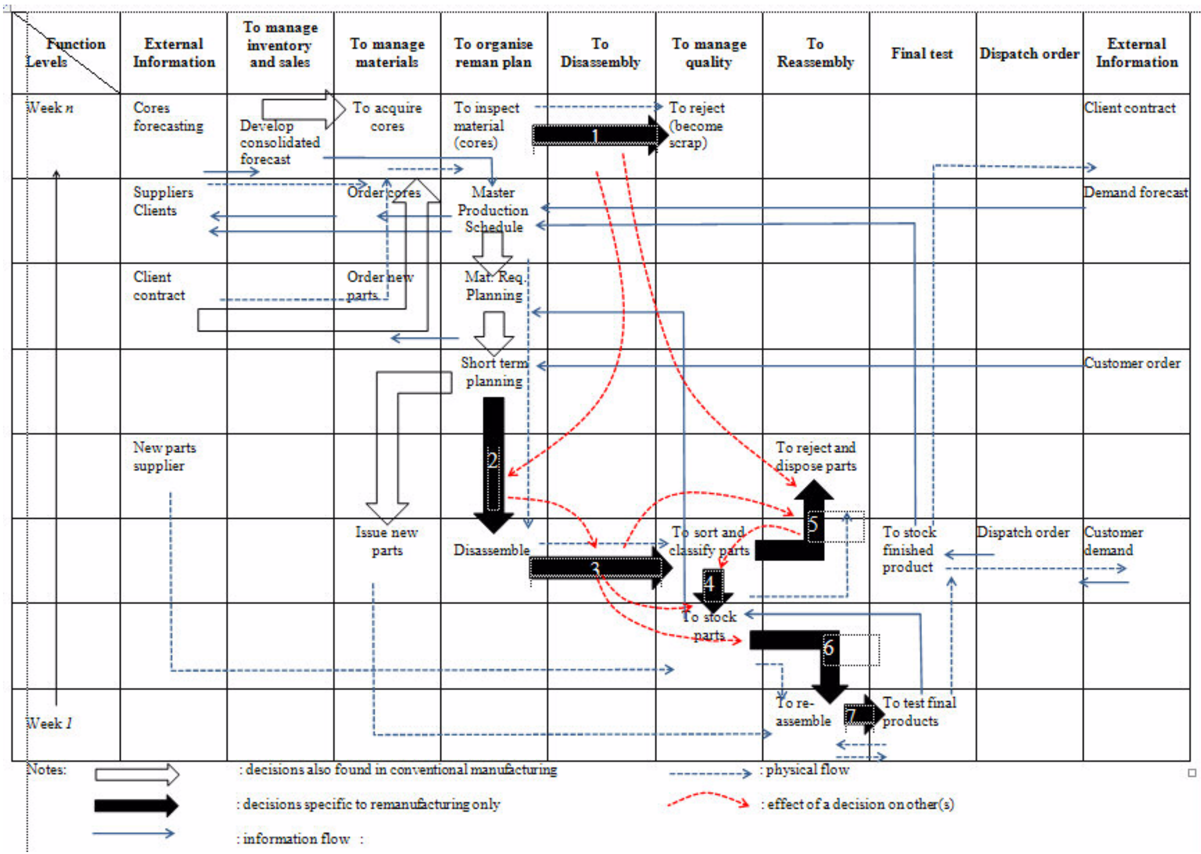


Figure 3 Material flow, information flow and interplays between decisions in remanufacturing

The findings of this study corroborate existing studies regarding the use of information technologies to assist with product recovery activities. Early studies questioned the role of information and communication technologies, as it was claimed that paper-based manual operations for product recovery activities are more efficient (Rogers & Tibben-Lembke, 2001). However, later investigation have found clearer evidence for the benefit of these technologies, primarily in reducing cost (Jayaraman et al. 2008) and increasing both economic and service quality-related performance (Daugherty et al. 2005). Numerous studies of the use of Radio Frequency Identification (RFID) have found that the technology improves collaboration and reduces distribution costs(Jayaraman et al. 2008), leads to better decision-making(Visich et al. 2007), increase recovered value(Condea et al. 2010) and reduces the number of customer claims (Langer et al. 2007).

Second, the managers of the case company engage in cross-functional collaborations. These collaborations are much needed due to the fact that almost all decisions in remanufacturing processes affect at least one other decision. Additionally, every stage of the remanufacturing process influences other stages. In some cases, the process is iterative in nature; for example, components that have been reassembled into a product that does not meet the required standards should be disassembled again.

Typically, a decision cannot be made by staff within one function without support from other functions. For example, the decision to buy new componentscannot be made by procurement staff alone; they must communicate with staff on the disassembly and inspection workstations, as they have a better understanding of how many components can be recovered. Using information provided by the disassembly and inspection workstations, procurement staff can make projections regarding how many new parts should be ordered.

This finding to some extent supports the findings of existing studies. Many people believe that that return management process mainly deals with physical product flow only.

In fact, equally important is the management of financial resources, the administrative process and information flows (Mollenkopf et al. 2011). For this reason, communications between different functions is necessary. Unfortunately, the kind of cross-functional work responsible for product returns is hard to find at top management level. As noted byMollenkopf et al. (2011), middle level managers within logistics and marketing are responsible for returns management; however, again, this group of managers lacks understanding of cross-functional work, defining inter-functional collaboration as just 'talking to each other'.

Third, the managers of the case company use historical data as the basis for their decision-making. In many cases, managers lack enough information to make sound decisions. To overcome this issue, managers rely on historical data and experiences to make decisions; for example, decisions regarding new components order releases and Material Recovery Rate (MRR). It is extremely difficult to make an accurate calculation of what the MRR of cores is. As MRR is related to new part orders release, the quality of information concerning MRR determines how accurate the orders are. Due to this uncertainty regarding the MRR, the company has to delay the release of lots until a minimum size batch has been accumulated from disassembly. To avoid delay, managers rely on their own experience to justify how many components should be ordered where information about the MRR has not been obtained.

CONCLUSION

This study proposed two research questions, which shed light on howdecisionswithin remanufacturing processes are made. There are four decisions that unique to remanufacturing processes, and theirinteraction with other decisions is also discussed. Due to the uniqueness of these decisions, the methods of decision-making that are commonly used in conventional manufacturing are less relevant in this context For this reason, a number of methods for making decisions are also identified in this study.

This study offers a novelty in the sense that it is the first time decisions in remanufacturing as well as their interplays are analysed in a comprehensive way. The use of GRAI Grid as a tool to display how the decisions affect one another has made it easy for researchers to understand. In qualitative research, selecting appropriate method for displaying the data is a critical part of the analysis as it determines how the data will be perceived in an objective way by different people (Whetten 1989). Thus, how the conclusion is drawn is also affected by the chosen method of displaying the data.

There are several research avenues that can be investigated in further research. This study finds that cross-functional collaboration is one of the methods used to overcome problems in decision-making under uncertainty in remanufacturing. However, how these collaborations work requires further analysis. Potential enquiries, such as identifying the enablers and inhibitors of collaborations, and analysing how the collaborations differ from those in conventional manufacturing are some examples of future investigation pathways.

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