Research on remanufacturing scheduling problem based on critical chain management

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Abstract. Remanufacturing is the recycling process of waste products as "as good as new products", compared with materials recycling, remanufacturing represents a higher form of recycling. The typical structure of remanufacturing system consists of three parts: disassembly workshop, remanufacturing workshop and assembly workshop. However, the management of production planning and control activities can differ greatly from management activities in traditional manufacturing. Scheduling in a remanufacturing environment is more complex and the scheduler must deal with more uncertainty than in a traditional manufacturing environment. In order to properly schedule in a remanufacturing environment the schedule must be able to cope with several complicating factors which increase variability. This paper introduced and discussed seven complicating characteristics that require significant changes in production planning and control activities, in order to provide a new method for remanufacturing production scheduling system.

Key word: Remanufacturing, DBR, critical chain, scheduling

1. Introduction
Remanufacturing is a life time cycle strategy that allows products which are no longer functional into the manufacturing process to be refurbished or disassembled into usable components or disposed. In other words, it is an industrial process that restores end-of-life goods to their original working condition. The largest remanufacturer in the world is The United States, and between 2006 and 2013, the value of U.S. remanufactured production grew by 15 percent to at least $43.0 billion, supporting 190,000 full-time jobs.

The remanufacturing-intensive sectors that account for the majority of remanufacturing activity include aerospace, consumer products, electrical apparatus, heavy-duty and off-road equipment, information technology products, vehicle parts, machinery, medical, furniture, restaurant equipment, and retreaded tires. Although In global market, country like China account for lots of remanufacturing activities, associated trade, and developing their own remanufacturing industries.

There is enormous complexity involved with developing remanufacturing operations. They are arguably more difficult than traditional manufacturing, such as forecasting the timing and quality of product returns and determining the optimal disassembly sequence(s) etc. Guide outlines the characteristics of significant and complex activities in production planning and control which are...
involved in remanufacturing: (1) the uncertain timing and quantity of returns, (2) the disassembly of returned products, (3) the uncertainty in materials recovered from returned items, (4) the need to balance returns with demands, (5) the stochastic routings for remanufacturing operations, (6) the complication of material matching restrictions, (7) the requirement for a reverse logistics network, and (8) highly variable processing times. Significant challenges are involved in remanufacturing scheduling, such as the selection of order release mechanisms, reverse logistics, lot sizes, and the priority of scheduling rules, restrictions in capacity, part commonality, the buffer inventories plan, multiple time periods scheduling, integration of forward and reverse manufacturing operations, etc.

Other researchers (e.g., Krupp, 1993; Brennan, Gupta.; Flapper et al., 2002) have noted other complicated issues and decisions involving remanufacturing scheduling, such as: the selection of lot sizes, order release mechanisms, priority scheduling rules, capacity restrictions, multiple products; the buffer size of inventories plan, scheduling over multiple time periods, integration of forward and reverse manufacturing operations, etc. and these are listed in Table 1.

Table 1 Remanufacturing scheduling complexities and issues

| Complexity/Issue                                                                 |
|---------------------------------------------------------------------------------|
| Need for a reverse, rather than forward, logistics network and operations       |
| Stochastic demands                                                             |
| Balancing returns with demand                                                  |
| Single vs. multiple stage operations                                           |
| In line vs. off-line rework                                                     |
| Resource availability and allocation                                           |
| Product structure considerations                                               |
| Sourcing decisions                                                             |
| Uncertain timing and quantity of core returns                                   |
| Uncertainty in material recovery rate                                           |
| Uncertain routing for materials and parts                                       |
| Lot sizing                                                                     |
| One versus multiple products                                                    |
| Order release mechanisms                                                       |
| Capacity restrictions                                                          |
| Priority scheduling rules                                                      |
| Scheduling for single vs. multiple time periods                                 |
| Scheduling methodology employed                                                 |

Guide (2000) describes a typical remanufacturing facility includes three main distinct operations: (1) disassembling, (2) remanufacturing/repair, and (3) reassembling.
In Figure 1 [1], the typical remanufacturing operations are following: First sorting the quality of reverse materials or products, enter in warehouse waiting for next progress. Disassembling separates the returned product into its components, or common materials. These are evaluated and determined to be acceptable for reuse, repairable, sold or discarded. Those reproducible parts and components are all enter in inventory for future recall or sent to the next operations. After reconditioning to a usable state the modules or parts are inventoried awaiting use or sent directly to the reassembly processes, where they are reassembled into products for resale and readied for finished goods inventory or shipment. As highlights on the complicating characteristics, the scheduling and control of each of these operations is an extremely challenging task. Figure 2 illustrates the three remanufacturing stages and their further analysis by production strategy. After the disassembling/remanufacturing/ reassembly of the product, there will be a preliminary check and classification. Parts and components will be sorted and identified in stock or wait for sale, which depends on the market needs. Classification is conducive to manage process and tracking, to enhance the level of information technology.
Figure 2. Remanufacturing stages and production strategy

Thus, this research is not only review the progress we have made in the scheduling and control of remanufacturing process, but also disassembly and reassembly operations. Actually, the integrated operations scheduling research also include single/multiple product, part commonality/no commonality, infinite/finite capacity, and deterministic/stochastic parameter organization, the purpose of remanufacturing research effort is to do more than just synthesis the progress made in the scheduling of disassembly, remanufacturing, and reassembly operations. To advance ability to schedule and control complexities mentioned in the literature; and focused in the whole close-loop chain. Our research is currently at review stage.

2. Remanufacturing literature

The purpose of this research is to synthesize the progress in the scheduling of disassembly, remanufacturing, and reassembly operations. Also to assess the ability to address the complexities mentioned in the literature; and to highlight additional research needs.

The recycling of waste products arrived at remanufacturing plant for a series of processes, such as cleaning, testing, surface repair, reprocessing, etc. Then remanufactured parts are assembled into products in the assembly shop. Three workshops will be involved in the production operation and scheduling problem, namely, disassembly scheduling, remanufacturing scheduling and reassembly scheduling. In Table 1, previous research on remanufacturing has addressed a variety of problems, and the relevant efforts be summarized to production planning and control. Furthermore a thorough discussion of this literature is available in Guide et al. 1999. While a number of topics have been reached in depth into the real remanufacturing scheduling by the existing body of knowledge, significant areas have not been addressed in previous works. The majority of these studies are limited to a specific functional activity, only a very limited number of case studies exist [2-3], and, such as scheduling. A number of characteristics that significantly complicate production planning and control activities may be inferred from the research literature. For instance, researchers proposed seven complicating characteristics in various forms. No one identifies more than three of the complicating characteristics, and most of the characteristics are only mentioned in passing. The seven characteristics are:

1. The uncertain timing and quantity of returns
2. The need to balance returns with demands
3. The disassembling degree of returned products
4. The uncertainty in materials recovered from returned items
5. The requirement for a reverse logistics network
6. The problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.
7. The complication of material matching restrictions.
Remanufacturing operations are highly variable because the amount of time required to perform the necessary operations is a function of the part, or parts, causing the unit’s failure and for that failed part, the cause and extent of the failure. Probabilistic routeings are the operations required to restore the part to functional operation capability and other standards. Probabilistic routeings are a subset of routeings required from a master set of possible operations. The likelihood of an operation being required is a function of the product service life and the work conditions the unit has been subjected to. In the model, the probability of an operation being required is assigned, based on the considerations above. For all probabilistic operations, the routeing represents a closed set of operations that occur in a fixed sequence, but each probability of each individual operation is a random variable. Because of those dynamic natures of scheduling policies, a basic structure of remanufacturing scheduling system was showed in figure 3.

**Figure 3.** Remanufacturing scheduling system

Some scholars divided the remanufacturing model is into four different categories: OEM (Original Equipment Manufacturer) mode, independent manufacturer mode, OEM contract service model of remanufacturing and manufacturing OEM / independent manufacturer of mixed mode from the perspective of product life cycle [3], in general, the mainstream research field divided into two forms:
independent remanufacturing system (Independent Remanufacturing System, IRmS) and manufacturing / Remanufacturing hybrid system (Manufacturing/Remanufacturing Hybrid System, M/RmHS). For Independent manufacturers, they can do of any brand of product remanufacturing without OEM authorization, which can not only keep the original logo, but also create their own remanufacturing trademark. Independent remanufacturer has no direct relationship with the original product manufacturers, based on market demand forecast to develop their own production plan, control the production schedule. The characteristics of this model is to create more varieties, the general use of professional production line for mass production, scale and high efficiency, high resource utilization, low cost of production, its cost contains obvious superiority. OEM recycles or call-backs the old pieces through revers supply chain from dealers and repair stations, those products will be use in remanufacture then sale through the OME’s after-sales service network. The characteristics of this model is it include the allocation of orders, balancing the production quantity, lot size, etc. between the new production and remanufacturing, to obtain the maximum profit.

3. Critical chain project management method

Compared with traditional manufacturing systems, there are a lot of uncertainties in the production scheduling of remanufacturing system [4]. In the manufacturing workshop, because the quality of recycling of waste products (such as the service life of wearing parts, etc.), the uncertainty caused by process parts re manufacturing process and process time, which makes the manufacturing workshop production scheduling is more complicated; and the processing route and time uncertainty caused by processing equipment the amount of task, it is easy to form the bottleneck of resources, and will continue to shift the bottleneck.

Under the condition of limited resources, how to arrange resources, solve the resource bottleneck problem, and fully consider the production process uncertainty on remanufacturing process scheduling, ensure the remanufacturing production smoothly, is a problem to be solved urgently.

The complexity of the manufacturing system is mainly shown in three aspects: the uncertainty of the process route, the uncertain processing time and the resource constrained problem. Taking into account the dismantling of each part after the cleaning, testing and other processes, to a certain extent, you can determine the process route.

At present, some research on the remanufacturing system has been optimized, such as Guide to carry out some research on Remanufacturing scheduling problem with static priority performance of remanufacturing system sharing workshop scheduling in the analysis. A hybrid genetic algorithm was proposed for the optimization of remanufacturing production planning, and the use of a priority random batch mechanism for its simulation [5]. Analysis of the effect of uncertainty to the quality of waste parts recycling remanufacturing production planning has great influence on the quality of that, remanufacturing enterprise profits by waste parts, and manufacturing enterprises are also affected by the number of used products [6].

Other applications, like an approximate optimal buffer setting method, are studied in the queuing problem of remanufacturing system. Some research testing to remanufacturing and repair as the research object, considering the uncertainties and products in remanufacturing system, to process, inventory constraints, using Lagrange relaxation method, get the demolition, repair and optimization of assembly operation time value. It has established a mathematical model of remanufacturing logistics, which is used to solve the uncertainty of product recovery time, quality and quantity. However, throughout these studies, we find that the process time and resource constraints are not considered in the process of re manufacturing scheduling.

Critical chain project management method (Critical chain method, CCM) is a new method developed in Guide on the basis of the theory of constraints (Theory of constraints, TOC), the key chain instead of the critical path, considering a sequence of work between precedence and resource constraints under the constraints of the project cycle, and through the project buffer, conveying buffer and resource buffer mechanism to eliminate the uncertainty the influencing factors of the project scheduling.
4. Problem description
Remanufacturing operations are composed of two types of routings: mandatory and probabilistic. As well as it highly variable, since the amount of time required performing the necessary operation is a function of the wear associated with a part. Remanufacturing Job Shop problem is similar to the classic one, remanufacturing production scheduling problem can be described as N parts to be processed, after clean and test process the remanufacturing routings have been identified, but the processing time is a random variable, obey a certain distribution; there are M machines at workshop. The purpose of scheduling is to arrange the optimal processing sequence and the start time of each work piece on each machine tool, in order to satisfy the process constraints of the machining process, the performance index of the remanufacturing system is optimal. The basic constraints in the processing process are as follows:
(1) All the routings must be processed on the specified machine and each process must be started before the process is completed.
(2) At a specific time a machine can only process a part.
(3) Different parts have the same priority.
The objective function is to minimize the mean flow time, namely to finish process in the shortest time.

5. Conclusion
Up to now, comparing reports in the field of remanufacturing scheduling is not easy for the variety of problems, objectives, and methods utilized. Defining a unanimously accepted set of problems with significant size and same complexities could make comparation more compelling.
The remanufacturing scheduling literature was classified into disassembly versus integrated scheduling, single versus multiple products. The complicating characteristics must be considered as a whole, rather than considering the effects of each characteristic separately. Remanufacturing firms must be able to manage complex tasks that are significantly different from tasks in a traditional manufacturing environment. After identify and describe those unique characteristics of scheduling and control for remanufacturing. Future work is suggested in development of approaches such as critical chain method which help reduce the variability in the whole remanufacturing chain, it may provide a dramatically huge challenge to reach trade-off multiple objectives, but result may in more useful solutions.

References
[1] Guide V.D.R Jr 2000 J. Oper. Manag. 18 467-83.
[2] Ferrer G 1997 Resour. Conserv. Recy. 19 221-55.
[3] Guide V.D.R Jr 2000 J. Oper. Manag.18(4): 467-483.
[4] Guide V.D.R Jr 2007 Int. J. Prod. Res. 34 1081-91.
[5] Li J, González M and Zhu Y 2009 Int. J. Prod. Econ. 117 286-301.
[6] Ferrer G and Whybark D C 2001 Prod. Oper. Manag. 10 112-24.