REMANUFACTURING SCHEDULING: RESEARCH PROGRESS, INDUSTRY PRACTICE, AND FUTURE NEEDS

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ABSTRACT

We review the academic progress made in remanufacturing scheduling and compare this to the actual remanufacturing planning and scheduling practices used in industry. We survey members of the Automotive Parts Remanufacturers Association (APRA) to learn the techniques and approaches they use to plan and schedule their remanufacturing operations and the difficulties encountered. Survey results are compared with academic progress in remanufacturing scheduling and the results of previous industry surveys.

Key words: remanufacturing scheduling, academic research, industry practice, survey

INTRODUCTION

Remanufacturing allows products that are no longer functional to reenter the manufacturing process to be refurbished or disassembled into usable modules, components, or materials or disposed. Numerous regulatory policies are exerting pressure on firms to produce in an environmentally responsible manner (i.e., ER Directive 2002/525/EC and EU Directives 2002/96/EC and 2003/108/EC). The profitability potential of remanufacturing has also caught the attention of firms with a recent estimate claiming $65 billion in sales with over $37 billion of this total produced from the automotive industry (Car Care Council 2005).

However, there is enormous complexity involved with developing and operating efficient remanufacturing operations. Guide (2000) outlines the characteristics that significantly complicate the production planning, scheduling, and control activities involved in remanufacturing as the uncertain timing and quantity of returns, need to balance returns with demands, the disassembly of returned products, uncertainty in materials recovered from returned items, requirement for a reverse logistics network, complication of material matching restrictions, stochastic routings for materials for remanufacturing operations, and highly variable processing times.

Academic progress has been made to identify the complexities and issues, report industry practice, and develop quantitative methodologies in remanufacturing scheduling. However, the rapid development and growth in remanufacturing warrants periodic assessment of the current state of the art within the academic and practitioner communities.

Therefore, the purpose of our research is to compare the academic progress made in remanufacturing scheduling with the scheduling procedures actually used by remanufacturers and from this analysis recommend future research efforts which may benefit both areas.

ACADEMIC REMANUFACTURING SCHEDULING PROGRESS

Remanufacturing Scheduling Methodologies

Twenty-five different quantitative methodologies (not to mention six categories of heuristics) have been employed to model and solve remanufacturing scheduling problems. Modified MRP approaches (MMRP) such as multiple repair plans (Panisset, 1988), additional bills of materials (Krupp, 1993), and reverse MRP (RMRP) (Gupta & Taleb, 1994) were the initial methodologies of choice for disassembly planning and were commonplace through the 1990's up to 2001.

Guide and his associates introduced the use of computer simulation to disassembly/remanufacturing scheduling, planning, and control throughout the 1990's. One benefit was that computer simulation could employ stochastic data. Much exploratory research on disassembly release mechanisms, priority dispatching rules, buffer inventory locations, the influence of product structure, and control mechanisms such as drum-buffer-rope (Guide, 1996) and flexible Kanban (Kizilkaya & Gupta, 1998) utilized computer simulation.

The mathematical programming (MP) era for remanufacturing scheduling emerged in 2002. Research utilizing linear (Ferrer & Whykbark, 2001), integer (Lee, Xirouchakis, and Zust, 2002), mixed-integer (Inderfurth & Langella, 2006), dynamic (Janiak et al. 2009), stochastic dynamic (Luh et al. 2005), goal (Kongar & Kupta, 2002), and fuzzy goal programming (Kongar & Gupta, 2006) appeared. Although mathematical programming demonstrates success in achieving optimal solutions for restricted test problems, heuristics may offer the most promise in solving realistically-sized scheduling problems. In fact recent developments in the use of heuristics showcases the use of multi-stage heuristic procedures (Luh et al. 2005 – stochastic dynamic programming and computer simulation; Kim, Lee, Xirouchakis & Kwon, 2009 - branch and bound; and Kim & Xirouchakis, 2010 - stochastic inventory model).

Other research strategies employing heuristics include proposing and testing several, rather straight-forward heuristics and determining which heuristic works best (near-optimal solution and computational efficiency) under specific circumstances/conditions/complexities (Raut et al., 2008; Janiak et al. 2009; and Teunter, Tang, & Kaparis, 2009). Authors claim that the heuristics, due to their simplified procedures, run very efficiently and, therefore, have practical implications.

Handling Uncertainty, Complexities, and Stochasticity

The complexities and uncertainties innate to remanufacturing are significant obstacles. In addition to Guide's (2000) "classical" remanufacturing complexities we include *product value deterioration*, (particularly relevant to the electronics industry), *product structure* - the returns of multiple products with various product levels, the number of children in root items, the number of items per child, etc. and a category denoted as *other* to incorporate additional uncertain issues (e.g., amounts stored and disposed).

Early efforts to address uncertain/stochastic elements use additional operational and marketing options such as multiple repair bills (Panisset, 1988), additional BOMs (Krupp, 1993), a modified Bill of Resources (Guide & Spencer, 1997), alternate remanufacturing alternatives (Souza, Ketzenberg, and Guide, 2002), and "sell-as-is" options (Souza & Ketzenberg, 2002). These multiple, deterministic options or scenarios were progressively augmented by stochastic techniques, the most prevalent of which has been computer simulation (Guide, Srivastava, & Kraus 1997, and Guide & Srivastava 1997, 1998). Computer simulation may be the most powerful methodology to aid in establishing (deterministic) managerial guidelines, scheduling rules, or procedures for actual scheduling.

Summary

Thus, academia has made progress in mathematically modeling and solving larger and more realistic scheduling scenarios simultaneously incorporating several of Guide's complexities and others such as product value deterioration. Objective functions have progressed from MRP-type objectives to performance–based, to including multiple, realistic economic costs, and even profits. While the complexities have been identified and some stochastically modeled, they have not yet all been addressed simultaneously in model formulations and solutions.

SURVEY DESIGN

To our knowledge the last, practitioner survey (Guide 2000) of scheduling techniques used by U.S. remanufacturers was completed over 12 years ago. To update our knowledge a survey instrument was designed and reviewed by the administrative staff of the Automotive Parts Remanufacturers Association (APRA). This questionnaire was distributed via mail to 791 firm members of the Automotive Parts Remanufacturers Association (APRA) and yielded a 6.2% response rate. A copy of the survey document is available from the authors upon request.

RESULTS

Survey Respondents and Business Data

More than 91% of the respondents are the owners or presidents of their companies. The average company has been in this business for over 37 years and the majority state that their engagement in remanufacturing is due to its profitability. Companies report multiple remanufacturing types of operations with most classifying themselves as remanufacture-to-stock (RTS)(95.4%), followed by remanufacture-to-order (RTO)(85.4%), (re)assemble-to-order (ATO)(20.7%), and finally other with 46.7%.

Demand Management

Two of the remanufacturing scheduling complexities mentioned in the academic literature are the unknown customer demands and the uncertain returns of cores. While Guide's survey (2000) indicated that 41% of firms attempt to balance returns with market demand, our survey indicates an increase with 75% percent of respondents stating that they try to balance cores with final demand. In addition 28.9% of respondents indicate that they track the material recovery rates (MRR) of parts.

Production Planning, Scheduling, and Control

Forty-two percent of our respondents report having MRP systems and of those roughly the same percentage also determined MRRs. Most companies (54.5%) affirm that they have a master production schedule (MPS) and that a JIT production control system (31.1%) is used. Almost all respondents (96.8%) state that scheduling is completed at essentially the work station level indicating the shop floor level (61.3%), work center level (32.3%), and machine level (3.2%). Only 19.4% report scheduling at the aggregate level.

A large percentage still use manual equipment/operations for disassembly (94.4%). However, while Guide (2000) reported no automated techniques in disassembly, we found 15.2% indicate (some) use of automated disassembly. Thus, it appears that the use of automated equipment in disassembly has increased and this progress is noteworthy.

All respondents report having manual operations, but 27.1% also mention use of (some) automated remanufacturing operations. This is an improvement over Nasr et al.'s (1998) finding of 17.4% use of CNC or NC equipment. Thus, we see some increased use of automated operations, not only in disassembly, but also in the remanufacturing operations.

The survey also asked companies about their priority control/expediting policies and late order deliveries. Over 77% state that they expedite orders and that, on average, 22.8% of orders are expedited. While, 18.1% of respondents state they deliver 100% on time, the average percent of orders delivered on time is reported to be 90.1%. Firms were also asked the reasons for late deliveries. At the top of the list is core/part availability (74.1%), followed by shipping/transportation delays (11.1%), and equally represented at 3.7% were unexpected damage, waiting for a large order, expediting other orders, and overseas suppliers. The aforementioned reasons account for nearly 93% of late orders.

Scheduling Difficulties and Obstacles to Growth

Respondents report eight scheduling difficulties, which we classify into three groups according to the frequency they are mentioned. The first set accounting for 40% of all respondents includes parts availability (the greatest difficulty) and employee quality and flexibility (ability to be retrained for new products. The second set accounting for 20% of all respondents incorporates difficulties in forecasting customer orders (common in RTO environments) and balancing product availability with market demand. The last set (12.5% of respondents) includes long lead times (for parts and cores), poor quality parts, on time delivery of parts, and conflicting priorities.

When probed for the greatest obstacles to growth in the next 10 years, respondents provide a list of 14 obstacles with the top five being parts availability (16.2%), competition from imported parts (16.2%), reliable, trainable technicians (13.5%), high utility and shipping costs (10.8%), and government regulation (8.1%). While differently ordered, these obstacles to growth reflect many of those mentioned in Guide's survey (2000) such as increased pressure to reduce lead times and the lack of cores.

CONCLUSIONS AND CONTINUING RESEARCH NEEDS

We have learned that many of the results from academic research (e.g., RMRP methodology and use of modules, priority scheduling rules, quantitative replenishment techniques such as EOQ and dynamic lot sizes, calculation and use of MRRs, quantitatively determined remanufacturing lot sizes, use of JIT, DBR, and usage of some automated disassembly and remanufacturing operations) have been deployed. Some of the more recent and sophisticated scheduling techniques have apparently not yet filtered (in abundance) to this commercial level. However, there are areas where academic research could be of further use to remanufacturers in the automotive repair parts industry.

Guide's survey (2000) revealed that 75% of the respondents believed that products are not designed for disassembly. Perhaps due to increased government regulations, the drive for greater sustainability, and the profit motive, only 44% of our respondents contend that products are *not* designed for remanufacturing. While an improvement, further progress in designing for disassembly and remanufacturing can be accomplished especially when OEMs do not have in-house remanufacturing capability.

The repeated mention of difficulties with parts availability, lead times, delivery speed, and late deliveries may signal the need for an effective and integrated "remanufacturing supply chain network". Remanufacturers need to be linked via computer to their core suppliers and major customers, where they can analyze customer forecasts, instantly receive customer orders, review supplier inventories and core/parts availability, and electronically send core and part purchase orders. We believe this should be studied for its technical and economic feasibility.

The simulations and models of remanufacturing scheduling and performance concern mainly technical data, operations, and decisions. However, this survey's respondents highlighted the importance of employee quality, reliability, and trainability. Thus, academia may be able to assist in researching the most effective screening techniques for applicants and the best means for retraining to remanufacture new and more sophisticated products.

While several of Guide's complexities/stochastic variables have been incorporated into scheduling models, all have not. Further research into models that incorporate more of these complexities would be very useful. We agree with Guide (2000) that individual complexities should be studied and also their interactions.

Thus, while academic endeavors and results have been increasingly incorporated into industry practice, we need to continue our efforts to download our progress to industry (e.g., use of MRRs in scheduling and purchasing decisions), further address the concerns they raise (e.g. employee issues, foreign suppliers, and internet competition [with the implications of remanufacturing outsourcing]), and aid in the development of computer-integrated remanufacturing supply chain networks to reduce demand and sourcing (both quantity and lead time) uncertainties. This may require additional academic/practitioner case-based research efforts and follow up industrial surveys.

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REFERENCES

Car Care Council, 2005. Remanufacturing: the original recycling [online]. Businessweek,. Available from: http://www.businessweek.com/autos/content/dec2005/bw20051230_058327.htm [Accessed on July 26, 2011].

Ferrer, G. and Whybark, D. C., 2001. Material planning for a remanufacturing facility. *Production and Operations Management*, 10 (2), 112- 124.

Guide, Jr., V. D. R., 1996. Scheduling using drum-buffer-rope in a remanufacturing environment. *International Journal of Production Research*, 34 (4), 1081-1091.

Guide, V. D. R. and Srivastava, R., 1997. Buffering from material recovery uncertainty in a recoverable manufacturing environment. *Journal of the Operational Research Society*, 48, 519-529.

Guide, V. D. R. and Spencer, M. S., 1997. Rough-cut capacity planning for remanufacturing firms. *Production Planning & Control*, 8 (3), 237-244.

Guide, V. D. R, Srivastava, R. and Kraus, R. E., 1997. Product structure complexity and scheduling of operations in recoverable manufacturing. *International Journal of Production Research*, 35 (11), 3179-3199.

Guide, V. D. R. and Srivastava, R., 1998. Inventory buffers in recoverable manufacturing. *Journal of Operations Management*, 16, 551-568.

Guide, V. D. R., 2000. Production planning and control for remanufacturing: industry practice and research needs. *Journal of Operations Management*, 18, 467-483.

Gupta, S. M. and Taleb, K. N., 1994. Scheduling disassembly. *International Journal of Production Research*, 32 (8),1857-1866.

Inderfurth K. and Langella, I. M., 2006. Heuristics for solving disassemble-to-order problems with stochastic yields. *OR Spectrum*, 28, 73-99.

Janiak, A., Krysiak, T., Pappis, C. P., Voutsinas, T. G., 2009. A scheduling problem with job values given as a power function of their completion times. *European Journal of Operational Research*, 193, 836-848.

Kim, H.-J., Lee, D-H. and Xirouchakis, P., Kwon, O. 2009. A branch and bound algorithm for disassembly scheduling with assembly product structure, *The Journal of the Operational Research Society*, 60 (3), 419-430.

Kim, H.-J. and Xirouchakis, P. 2010. Capacitated disassembly scheduling with random demand, *International Journal of Production Research*, 48 (23), 2010, 7177-7194.

Kizilkaya, E. and Gupta, S. M. 1998. Material flow control and scheduling in a disassembly environment. *Computers and industrial Engineering*, 35 (1-2), 93-96.

Kongar E. and Gupta, S. M. 2002. A multi-criteria decision making approach for disassembly-to-order systems, *Journal of Electronics Manufacturing*, 11(2), 171-183.

Kongar E. and Gupta, S. M. 2006. Disassembly to order system under uncertainty. *Omega*, 34, 550-561.

Krupp, J. A. G. 1993. Structuring bills of material for automotive remanufacturing. *Production and Inventory Management Journal*, Fourth Quarter, 46-52.

Lee, D-H., Xirouchakis, P., and Zust, R. 2002. Disassembly scheduling with capacity constraints. *CIRP Annals-Manufacturing Technology*, 51 (1), 387-390.

Luh, P.B., Yu, D., Soorapanth, S., Khibnik,A. I. and Rajamani, R. 2005. A Lagrangian relaxation based approach to schedule asset overhaul and repair services. *IEEE Transactions on Automation Science and Engineering*, 2 (2), 145-157.

Nasr, N., Hughson, C., Varel, E. and Bauer, R., "State-of-the-Art Assessment of remanufacturing Technology –draft document. Rochester Institute of Technology, National Center for Remanufacturing, Rocheseter, NY. 1998.

Panisset, B. D. 1988. MRP II for repair/refurbish industries. *Production and Inventory Management*, 29 (4), 12-15.

Raut, S., Gupta, J.N.D. and Swami, S. 2008. Single machine scheduling with time deteriorating job values. *Journal of the Operational Research Society*, 59, 105-118.

Souza, G. C., Ketzenberg, M. E. and Guide, V. D. R. 2002. Capacitated remanufacturing with service level constraint. *Production and Operations Management*, 11, 231-248.

Souza, G. C., and Ketzenberg, M. E. 2002. Two stage make-to-order remanufacturing with service level constraints. *International Journal of Production Research*, 40 (2), 477-493.

Teunter, R., Tang, O. and Kaparis, K. 2009. Heuristics for the economic lot scheduling problem with returns. *International Journal of Production Economics*, 118 (1), 323-330.