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Centralization or decentralization of remanufacturing facilities in an after-market service supply chain

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Abstract. Equipment manufacturers are increasingly selling complementary services such as remanufacturing services to their equipment customers. This servitization trend mandates that the remanufacturing supply chain network is optimized accordingly. In order to set up such network, investment decisions have to be made, not only regarding the number, locations and types of remanufacturing facilities, but also with respect to the appropriate capacity and inventory levels in order to guarantee a specific service level. These network decisions are influenced by the way remanufacturing services are offered. We consider here two service delivery strategies: either a quick exchange of the used part by an available refurbished one or re-installing the original part when all corresponding remanufacturing processes are finished. Given the high level of uncertainty in this context, we build a stochastic, profit maximizing model to simultaneously determine the optimal layout and the optimal service delivery strategy for a multi-level logistics network with single indenture repairable service parts. Model results for this case study are obtained by the differential evolution algorithm.

1 Introduction

In many mature markets, the large amount of machinery installed provides an opportunity to develop profitable maintenance service supported by significant remanufacturing activities [WB99, CL13]. Consequently, an increasing number of companies like Bosch and HP is intensifying their remanufacturing activities [GSWB06]. Our case-study company is an international original equipment manufacturer (OEM) of industrial equipment with a renewed focus on remanufacturing. Due to confidentiality reasons the company is referred to as AirCorp and financial specifications are omitted.

To set up a remanufacturing network, AirCorp has to decide upon the number, locations and types of remanufacturing facilities. Moreover, the appropriate capacity and inventory levels have to be set in order to satisfy the service levels set in the service contract. Furthermore, how the service will be delivered and other contractual arrangements like the part ownership will all have an impact on the optimal remanufacturing network. We develop a model that supports this complex decision making process.

2 Problem Description

AirCorp offers its customers a refurbishment service of the key component of the equipment it has sold: during refurbishment the part is cleaned, rebeared and restored to an as-good-as-new condition which will not only extend the life of the equipment, but also increase energy efficiency. The refurbishment itself takes place in a dedicated facility, i.e. a remanufacturing center. Because the machinery built by AirCorp is stationary, an AirCorp field technician has to travel to the customer to disconnect the worn-out part. There are two possible strategies to deliver the service: a refurbishment with an exchange and without an exchange. Under a refurbishment with exchange, further referred to as an "exchange strategy", the technician replaces the part by an already refurbished one. Contrary, if a refurbishment without the exchange option is selected, or shortly a "refurbishment strategy", the customer has to wait until its own part is refurbished and the field technician re-visits the site to install the part. With the exchange strategy, the company has to replace the worn-out part by a part taken from stock. This inventory of as-good-as-new parts is replenished either by refurbished parts from previous customers or by newly produced parts if the return volume is not sufficient to fulfill demand due to scrap or other sources of loss. The inventory can be held at the remanufacturing facilities or at a centralized distribution center (DC).

There are five potential locations to open a remanufacturing center, corresponding to five service regions. In each of these service regions hundreds of customers are located. In order to manage the data requirements and limit the model complexity, customers who are geographically dispersed can be clustered into five locations corresponding to the five service regions. Hence, for each region we have one customer location in which the demand is concentrated. Traveling times to these locations are set to the average travel times within the corresponding region. While the locations of the remanufacturing facilities are to be determined, the current locations of the production plant (for delivery of new parts) and the centralized distribution center are not to be altered. Customers of different regions differ in their preference for the two service delivery strategies. In some regions the exchange service can be sold with a premium, while in others customers value the exchange service equally to the refurbishment service. We include these regional difference by different demand and price levels between the customer regions. These data were obtained by contacting the regional AirCorp offices. Clearly, the most profitable service delivery strategy might differ between the regions. Determining the optimal service delivery strategy within the separate regions is an important objective of our model.

Designing our remanufacturing network involves three related sub-problems: a facility location, a capacity and an inventory sub-problem. The first decision is where to open remanufacturing facilities. The second decision deals with the number of operators that should be employed at each facility. The third decision sets the appropriate inventory level subject to a given service level. How much inventory to carry will be greatly influenced by the chosen service delivery strategy. In the exchange strategy an inventory of already refurbished parts is required, while the refurbishment without exchange does not require such an investment. Apart from the inventory level, also the location of this inventory may be different.

Due to the interactions between the decisions with respect to facilities, capacities, inventories and the service delivery strategy, we take an integrated solution approach. Moreover, uncertainty in demand, processing and transportation times is taken into account by use of queuing theory. The resulting model is a mixed integer non-linear model that integrates queueing relationships and a profit maximization objective. We solve the model by a differential evolution search algorithm. Section 2.1 clarifies the model and presents the results of the case study. We conclude in Section 3.

2.1 Model and Results

The major contribution of this paper is its multi-disciplinary approach: we simultaneously solve a facility location, capacity and inventory problem. To the best of our knowledge, only [RVR09] and [vOBS06] have succeeded in simultaneously solving these problems, while taking into account uncertainty. Contrary to this earlier work, we consider two delivery strategies, i.e. exchange vs. refurbishment. We maximize profit because both costs and revenues depend on the selected delivery strategy. A profit maximizing objective is scarcely studied in reverse logistics networks [MNSdG09]. Consequently, the profit-orientation of our model can also be considered as a valuable contribution to the field of network design for remanufacturing activities. Lastly, the relevance and solvability of the problem is proven by the case-study. AirCorp uses the stochastic mixed integer non-linear model to support their network decisions. Next, we briefly present the integrated modeling approach for each of the three sub-problems mentioned above and explain the optimization procedure.

In the facility location sub-problem, we consider a multi-echelon network with multiple facility types that can be opened at locations chosen from a fixed, predetermined set of locations. We apply the model in a European context that consists of five service regions. In each service region, there is a potential location for opening a remanufacturing center. The stochastic nature of transportation times between nodes and demand that originates from the regions is modeled by assuming general and Poisson distributions, respectively. During the remanufacturing process, returned units from customer locations are restored to an as-good-as-new condition. Due to some level of scrap, demand for remanufactured parts is satisfied by new parts that are manufactured at the production plant. Both lead time calculations and routing decisions take into account the parts from both remanufacturing centers and the production plant. Facility location decisions determine the feasible flows of parts through the network: a part can only pass through a facility if it is opened. These flows are defined as routings, i.e. a sequence of facilities that each part will visit between the nodes where it enters and leaves the network.

In the capacity sub-problem, the optimal number of workers in each remanufacturing center is determined by considering the selected routings and the committed service levels. Queueing theory provides us with the relationships to link the demand volume and variability with the capacity requirements and lead times [HS00]. The reverse logistics network can be considered as a queuing system that consists of stochastic arrival and remanufacturing processes. M/G/m queues are used at the first level in the network, while G/G/m queues are used at other levels. Approximations that apply to a system under heavy traffic conditions with multiple parallel servers are used from [Whi93]. Hence, we take into account the trade-offs between capacity and lead time.

From an inventory perspective, there is a significant difference between the two service delivery strategies. In contrast to the refurbishment strategy, i.e. without exchanging parts from inventory, the exchange strategy requires an additional investment in inventory of parts that have finished the remanufacturing process. This additional investment can be justified by a higher selling price and/or savings in traveling for field technicians. Inventory of remanufactured parts is managed according to a continuous review one-for-one replenishment policy. Next to this inventory of remanufactured and finished parts, Little's Law is used to calculate the lead time dependent work-in-process inventory, which is obviously present in each network design regardless of the implemented service delivery strategy.

We solve the three sub-problems in an integrated way by evaluating the profit impact of the different decisions. The decision on the selected service delivery strategy affects revenue through different selling prices that apply. Total costs consist of facility costs, transportation costs, capacity (operator) costs, scrap costs, variable remanufacturing costs and field technician costs for traveling and wrenching. The resulting profit function is the objective of the mixed integer non-linear model. We opt for a differential evolution algorithm to solve this NP hard problem to optimality [BA02, LZ99, LV07, LV12].

In the case study, we optimize the network for different realistic scenarios of prices and volumes. Overall, the optimal network has always one echelon, i.e. parts are transported directly form the customer to an all-round facility and back to the customer. The possibility to use a dedicated centralized distribution center is not selected by the model. Next, we observe that demand volume is the key determinant for the level of centralization: whereas the number of remanufacturing facilities is limited with low demand, the number rises significantly with increasing demand levels. An important observation for AirCorp's management is that from a profit perspective, opening too many facilities is less detrimental than opening too few facilities (see Figure 1). Increasing demand levels also justify hiring more operators, while the optimal utilization rates of these operators increase.

As expected, the relative selling price of an exchange service plays a key role to determine the optimal service delivery strategy. Whereas the refurbishment strategy is preferred at low price levels for an exchange strategy, regions will switch towards an exchange strategy as its relative price increases. Interestingly, while switching to an exchange strategy, the optimal utilization rate of the operators goes down. Here the queueing dynamics are at play: lower utilization

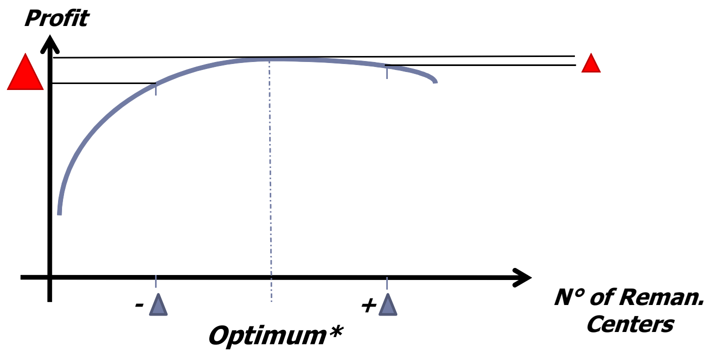

Fig. 1. Impact of the number of facilities on profits.

rates equal shorter lead times. Due to the higher inventory requirements of an exchange policy, shorter lead times are especially advantageous because some expensive inventory holding costs can be avoided. In the exchange strategy, the potential savings in inventory are in favor of a higher investment in capacity and consequently target lower utilization levels in order to reduce the lead time of the remanufacturing process. Since the optimal network structure and the capacity level are influenced by the choice of the service delivery strategy, we emphasize the need to simultaneously analyze the network and service contract design.

3 Conclusions

In this paper we optimize the remanufacturing network design and the delivery strategy in order to maximize profits. Apart from the choice between two service delivery strategies and the profit perspective, our contribution lies in the simultaneous solution of three related network design problems, i.e. the facility location problem, the capacity and the inventory problem. In our case study we determine the optimal number, type and location of remanufacturing facilities for an international OEM. Variability in both demand and processing times is taken into account by integrating queuing relationships into the model. The mixed integer non-linear model is solved by a differential evolution search procedure. The case study results reveal that volume is key to determine the optimal number of facilities. Another observation is that the sales price determines the choice of the service delivery strategy. Furthermore, this choice also impacts the optimal capacity levels: exchange services require higher capacity investments in the remanufacturing centers. Hence, there is a clear need to simultaneously analyze the design of networks and the service delivery strategy. These results highlight the importance of taking an integrated approach by combining inventory, capacity, investment and service delivery decisions. Multiple extensions to our research are possible e.g. the impact of transportation batching. However, the model can be applied to many settings thanks to its general distributions for both transportation and remanufacturing times and the possibility to use multiple part classes, multiple resources and multiple network echelons.

References

[BA02] BV. Babu and R. Angira. A differential evolution approach for global optimization of MINLP problems. *Proceedings of 4th Asia-Pacific Conference on Simulated Evolution And Learning*, 2:880–884, 2002.

[CL13] P.J. Colen and M.R. Lambrecht. Product service systems: Exploring operational practices. *Service Industries Journal*, 33(2):forthcoming, 2013.

[GSWB06] V. Daniel R. Guide, Gilvan C. Souza, Luk N. Van Wassenhove, and Joseph D. Blackburn. Time value of commercial product returns. *Management Science*, 52(8):1200–1214, August 2006.

[HS00] W.J. Hopp and M.L. Spearman. *Factory Physics*. The McGraw-Hill Companies, New York, 2000.

[LV07] K. Lieckens and N. Vandaele. Reverse logistics network design: The extension towards uncertainty. *Computers and Operations Research*, 34(2):395 – 416, 2007.

[LV12] K. Lieckens and N. Vandaele. Multi-level reverse logistics network design under uncertainty. *International Journal of Production Research*, 2012. forthcoming.

[LZ99] J. Lampinen and I. Zelinka. *Mechanical Engineering Design Optimization by Differential Evolution*, chapter 8, pages 127–146. McGraw-Hill, London, 1999.

[MNSdG09] M. T. Melo, S. Nickel, and F. Saldanha-da Gama. Facility location and supply chain management - a review. *European Journal of Operational Research*, 196(2):401–412, 2009.

[RVR09] J. A. Rappold and B. D. Van Roo. Designing multi-echelon service parts networks with finite repair capacity. *European Journal of Operational Research*, 199(3):781–792, 2009.

[vOBS06] J. C. W. van Ommeren, A. F. Bumb, and A. V. Sleptchenko. Locating repair shops in a stochastic environment. *Computers & Operations Research*, 33:1575–1594, 2006.

[WB99] R Wise and P Baumgartner. Go downstream: The new profit imperative in manufacturing. *Harvard Business Review*, 77(1):133–141, 1999.

[Whi93] W. Whitt. Approximations for the GI/G/m queue. *Production and Operations Management*, 2(2):114–161, 1993.