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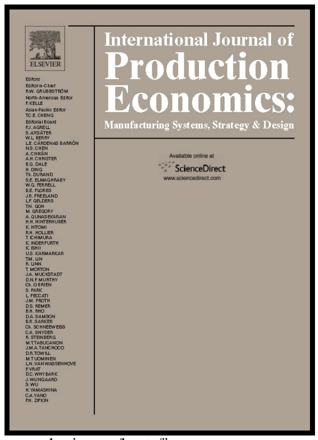

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Production and setup policy optimization for hybrid manufacturing-remanufacturing systems

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Abstract: Hybrid systems that use both raw materials (manufacturing mode) and returned products (remanufacturing mode) as a supply for their production process are considered. The system studied consists of one facility that necessitates setup for switching from one production mode to another. As in industrial practice, the flow rate of returned products is usually below the market demand, switching from one mode to another is unavoidable for meeting the demand. Therefore, determining the optimal production and setup policies is critical for effectively planning production process and reducing the manufacturing cost. Evaluating system performance, we take into account production costs in manufacturing and remanufacturing modes, serviceable and return inventory costs, backlog and setup costs. We present first an analytical solution for optimal production and setup schedule along the *production cycles*, considering the case of reliable systems. These cycles are shown to contain intervals of production at maximal rates as well as *on-demand* manufacturing and *on-return* remanufacturing. Next, for failure-prone systems, the optimality conditions in the form of Hamilton-Jacoby-Bellman (HJB) equations are developed. Solving HJB equations numerically, the optimal production and setup policies are calculated, and it is demonstrated that the optimal trajectories converge to the *production cycles)* of the type determined analytically beforehand. The sensitivity analysis of the obtained solutions (both analytical and numerical) over system parameters is presented to validate the proposed approach and demonstrate the robustness of the results.

Keywords: Manufacturing, remanufacturing, setup, optimal scheduling, limit cycle, numerical methods.

Hybrid manufacturing-remanufacturing systems are characterized by the presence of return flow of products along certain phases of production process additionally to the conventional (direct) one. The production planning and inventory control in such systems is an important domain of research. Increasing the volume of return flows induced by the environmental considerations as well as by the cost saving possibilities reinforces the importance of its effective management usually referenced as reverse logistics (*RL*). The integration of *RL* into the production environment attracted the researchers' interest since the nineties. In (Fleishman et al, 1997), authors describes the emerged reverse logistics as an activity encompassing various ways of returning used products back to the market. *RL* is composed of the forward channel directed from the suppliers to the manufacturers and then to the consumers, and the reverse channel directed from the consumers to the suppliers. Also, *remanufacturing* is recognized as a particular form of *RL* characterized by the added value recovery. The review of several case studies can be found in (De Brito et al, 2003) and the detailed analysis of the models used in *RL* and in remanufacturing is presented in (Dekker et al, 2004). The comprehensive review (Govindan et al, 2014) provides an exhaustive classification of the articles addressing remanufacturing in close loop supply chains and reverse logistics published after 2007. The critical review (Souza, 2012) classifies the literature in terms of strategic, tactical or operational issues and for tactical issues (acquisition, production, disposal policies) focuses on the underlying assumptions, results and open problems.

Rigorous analysis of optimal production planning and inventory control problems for remanufacturing systems without failures can be found in the literature. In particular, in (Dobos, 2003) the analysis is performed in continuous time and optimality conditions are derived. In (Inderfurth, 1997), the analysis is performed in discrete time and the importance of lead times for coordination of manufacturing and remanufacturing policies was demonstrated. Optimal policies were shown to be *of the critical level type* (often referenced to as a *(s,S)-policy* in inventory control literature and as a *hedging-point-policy* in production control literature). Further analysis of optimal policies addressing computational aspects and previously neglected cases was given in (Kiesmuller and Scherer, 2003). In (Kenne et al, 2012) the authors proposed a

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