Chapter 9

Directions for future research

In this thesis we have investigated the processes that are relevant in inventory control with remanufacturing. From the literature on mathematical models for production planning and inventory control (Chapter 3) we made a selection of models that seem applicable in the context of remanufacturing. However, even for this selected set of models we found that a number of relevant processes are not modeled, or modeled to a limited extent only. Some of the missing model components are listed below:

- *multi-level product structures* (i.e., multiple products and/or multi-component products). All models assume a single level product structure (i.e., one product that consists of a single component only). Therefore, disassembly of returned products and assembly of new products is not considered. Consequently, the applicability of these models in an MRP environment is only limited. Research on how to determine appropriate lot-sizes and safety-stock levels in a multi-level (MRP) environment with remanufacturing seems to be very useful (see also Brayman [8]),

- *dependency of demand and return processes.* In the models considered, market demands and market returns are either completely independent, or completely dependent. The only exception on this assumption is the model by Simpson [49] and the model developed in this thesis (Chapter 4). Here, demands and returns may occur because of product replacements, in which case there is perfect correlation between returns and demands, whereas the other returns and

demands are not caused by replacements, in which case no correlation exists between returns and demands.

Another relevant type of correlation between returns and demands is *temporal correlation.* If we have information about the time to return of sold products. we may use this information to control the (re)manufacturing and inventory processes more efficiently. Further investigations into how information about the time to return can be used, what kind of control policies would be appropriate, and how these policies relate to the policies we have implemented in this thesis would be useful.

- *demand and return quantities.* All continuous review models, except Heyman (1977), consider return and demand quantities to be equal to one product per occurrence. Any more general assumption would complicate model analysis considerably. However, as unit demands and unit returns do not always occur in practice, further research on models in which this assumption is relaxed seems worthwhile,

- *interactions between remanufacturing capacity and production capacity.* Most models consider outside procurement instead of internal production. Therefore, the capacity interactions between remanufacturing and production are disregarded. However, these capacity interactions may be significant in manufacturing companies that produce internally. Consequently, any research to analyze these capacity effects would be very interesting,

- *service.* All models, except the periodic review model of Kelle and Silver [30] and the continuous review model by Van der Laan [58], consider service in terms of backlogging costs. However, in practice backlogging costs are difficult to specify. Modeling service in terms of a, usually easier to specify, service level seems therefore a fruitful research topic,

- *control policy.* Simpson [49] has carried out research to identify an optimal control strategy for a periodic review model, under the assumption of zero remanufacturing and procurement lead-times, and zero fixed procurement costs. Inderfurth [26] extended Simpson' s model with non-zero lead-times and identified the optimal policy for some special cases. Heyman [23] has proved optimality of a continuous review single parameter disposal strategy, also under the assumptions of zero remanufacturing and procurement lead-times, and zero fixed

procurement costs. As far as we know, no other research has been carried out to identify optimal control policies under more general model assumptions. Any research in this direction would be very useful,

- *disposal costs.* Except in cash-balancing models, no other models consider fixed disposal costs, and related to this, no other models consider the problem of determining the disposal batch size.

This thesis is meant as a first attempt to structure the (inventory control) literature on remanufacturing, and to obtain some insights into the effects that remanufacturing may cause on production planning and inventory control. However, as may be clear from the discussion above, a lot of research remains to be done in this new and challenging field.