# Chapter 8

# Case study: Volkswagen

Volkswagen Germany has a long tradition in remanufacturing. Already in 1947 Volkswagen implemented a system to reuse a small set of car parts. Very rapidly this turned into a big set of reusable car parts and at the end of 1948 the first 'beetle'-motors could be made suitable for reuse. The success of the implemented remanufacturing concept resulted in a separate remanufacturing facility in Kassel, Germany, which is still in use today. At the moment, 1600 different car parts are being remanufactured.

Since the model we developed in Chapter 3 closely resembles the remanufacturing situation at Volkswagen Kassel, we used real life data as provided by Volkswagen to illustrate some theoretical findings of the foregoing chapters. To do so, the *actual situation* (see Figure 8.1) as specified by Volkswagen, serves as a basis for a simulation model.

## 8.1 Development of the simulation model

The actual situation of the HMR system (see Figure 8.1) may be characterized as follows:

- **Demand and return process.** The National Importer Organizations (NIO), which directly deliver to the car sellers, demand car parts from Kassel (flow $D_1$ in Figure 8.1). Kassel and the NIO have made the agreement that each part demanded by the NIO has to be followed by a product return (flow $R_1$) within a certain time interval. Despite of the agreement, this may not always be the case. As a consequence, there may be demands out of the system (flow $D_2$) that are not followed by a return. To be less dependent of the uncertain return flow from the NIO, VW Kassel is planning to implement another source of remanufacturable parts (flow $R_2$) in the near future. This external source will be independent from VW Kassel.

Product demands and product returns are not unit sized but occur in batches. This makes the analysis of this HMR system fundamentally different from our theoretical model. Since our interest is in real system behaviour we choose to analyze this system by means of simulation instead of using extra assumptions to fit it into our theoretical model.

- **Remanufacturing process.** In the actual situation there are two stocking points for remanufacturable car parts. Remanufacturable parts are first collected at a stocking point in Kassel ($S_1$). From time to time parts are transported from $S_1$ to a stocking point at an external remanufacturer ($S_3$). This stock is used as safety stock for the remanufacturing process.

  The remanufacturing process is controlled by monitoring a certain buffer stock. This buffer stock is the number of remanufacturables in Kassel minus the number of parts that are already planned to be delivered to the remanufacturer. If a car part is first introduced this number is expected to be relatively low. Two years after introduction, the objective is to keep this number constant at three months of average demand. If this number tends to become 'too high', a remanufacturing batch (flow $P_r$) may be triggered. If this number tends to become 'too low', a manufacturing batch (flow $P_m$) may be triggered.

- **Manufacturing process.** The serviceable inventory in Kassel may be regularly replenished by the manufacturing of new parts (flow $P_m$). The manufacturing batch size is not necessarily fixed. The manufacturing lead-time is stochastic.

- **Disposal process.** In the actual situation, the stocks of remanufacturables are controlled by monitoring the buffer stock that was mentioned earlier. If this number becomes 'too large', a certain number of remanufacturables may be sold or disposed off (flow $X$).

- **Service.** Stockouts occur if a serviceable part is demanded from Kassel (flows $D_1$ and $D_2$), but $S_2$ is out of stock. Every time that this happens, the demanded part is backordered and a fixed penalty per occurrence has to be paid.

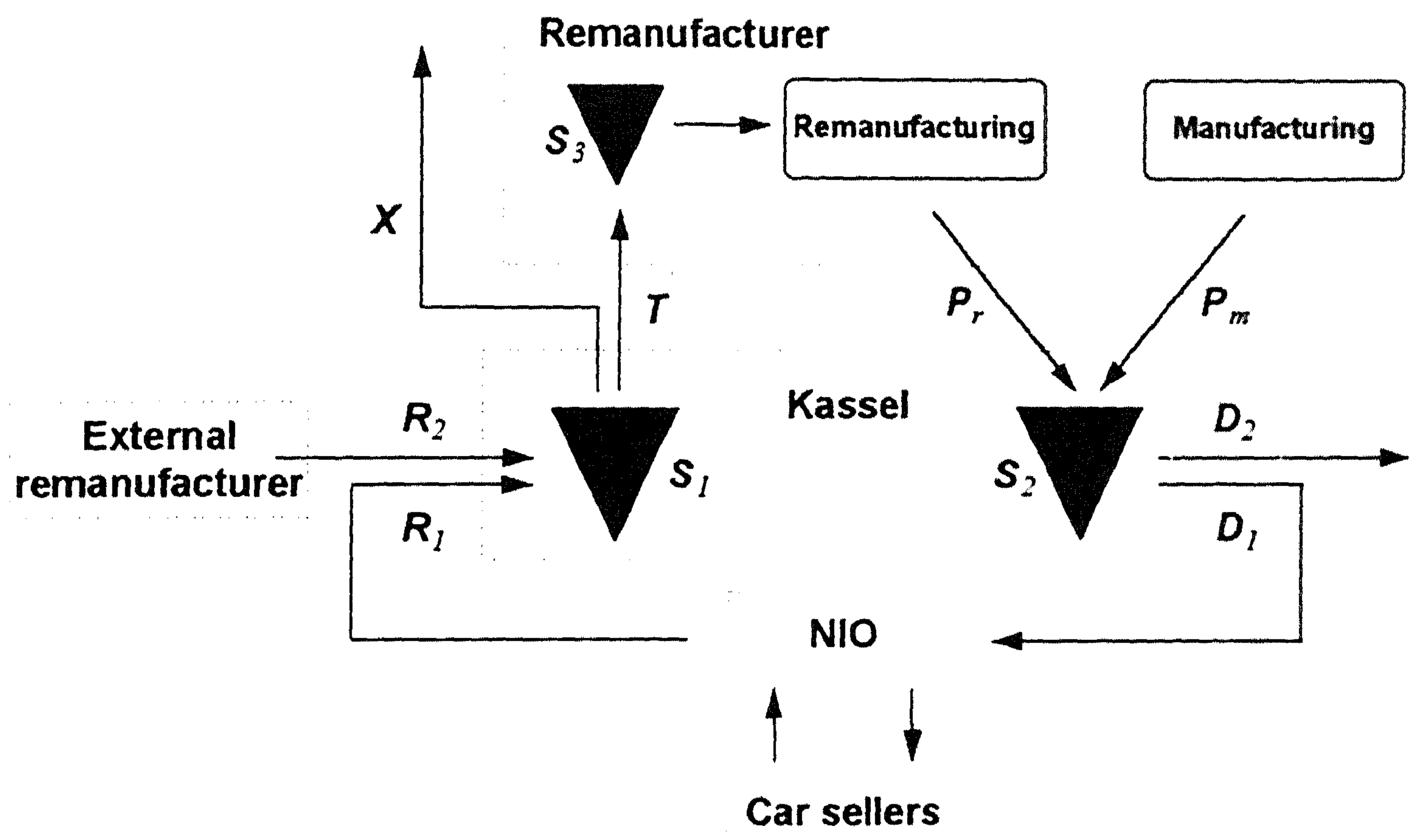


**Figure 8.1.** *A schematic representation of the actual situation at Volkswagen.*

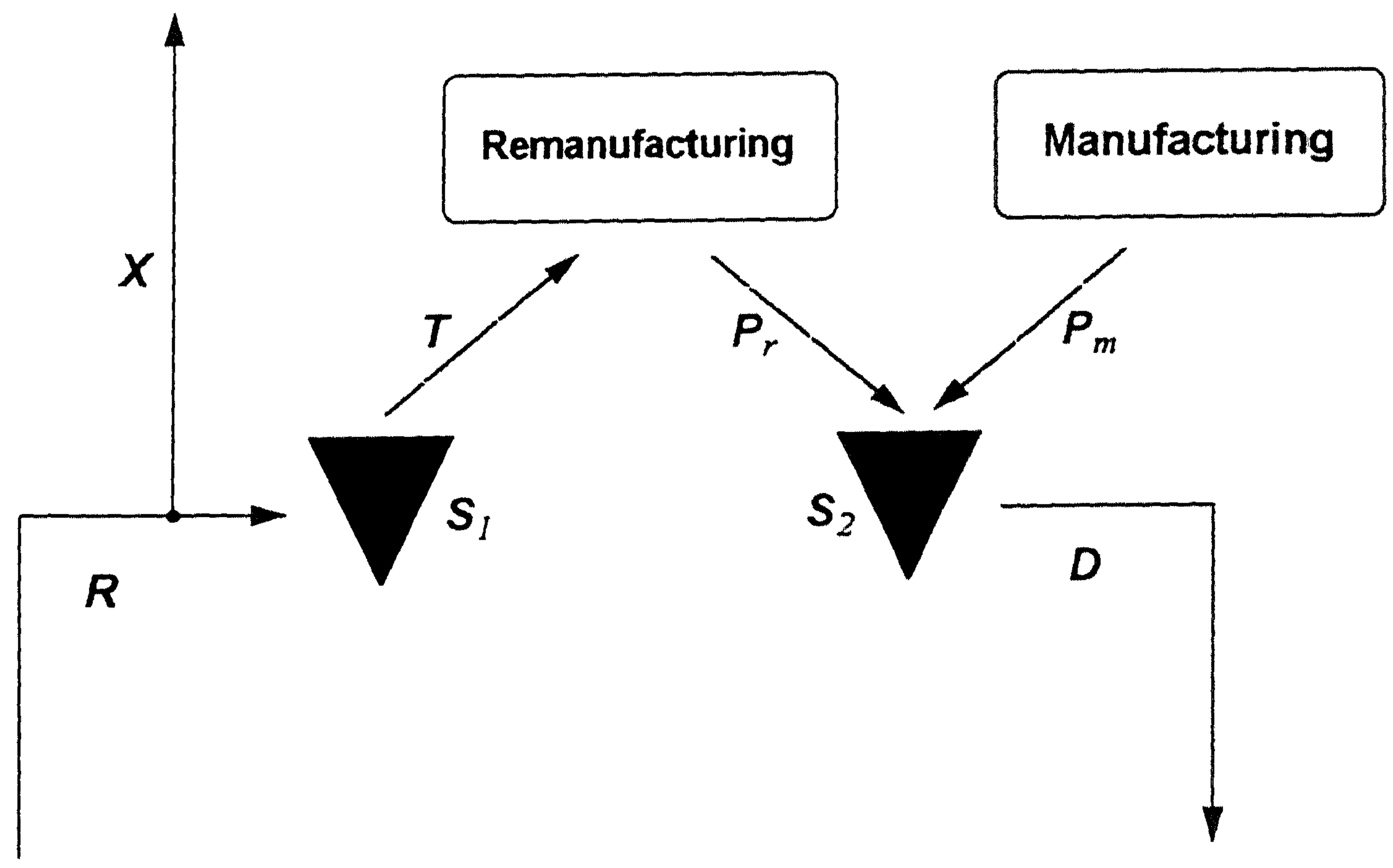


**Figure 8.2.** *A schematic representation of the simulation model based on the actual situation at Volkswagen.*

Although the actual situation at Volkswagen Kassel has many similarities with the theoretical HMR systems that we studied in Chapter 3–6, it mainly differs in that the product demands and returns are not unit sized and rather variable. Adapting the mathematical analysis to this situation is possible and even straightforward, but the size and complexity of the Markov chains involved would become too large to be practical. Instead we formulate the actual situation at Volkswagen Kassel in terms of a simulation model (See Figure 8.2). To do so, the following assumptions need to be made:

- **Demand and return process.** We aggregate the car sellers and the National Importer Organizations (NIO) into a single entity. By doing so we can discard the product flows between NIO and the car sellers and concentrate on the demand flow from Kassel to NIO ($D_1$) and the return flow to Kassel from the NIO ($R_1$). Since in principle every product demanded by NIO has to be followed by a product return, the occurrence of a product return is correlated with the demand occurrence of that particular product. Because of the time that passes however between these occurrences, it is not unrealistic to assume that the *timing* of a return is uncorrelated with the timing of its associated demand. As a consequence we can aggregate the demand flows $D_1$ and $D_2$ into one demand flow $D$, i.e., $D = D_1 + D_2$.

  At the time of the study the external source of remanufacturable parts was not yet implemented in practice. Therefore, we can disregard flow $R_2$ and continue with flow $R = R_1$ as the only resource of remanufacturable car parts.

- **Remanufacturing process.** In the actual situation there are two stocking points for remanufacturable parts. Returned parts from flows $R_1$ and $R_2$ are first collected at a stocking point in Kassel ($S_1$). From time to time parts are transported from $S_1$ to a stocking point at the remanufacturer ($S_3$). This stock is used as safety stock for the remanufacturing process. However, in our simulation model this stocking point is not really relevant, since to control the remanufacturing process we use a PULL type policy, whereas the transportation time was said to be negligible relative to the remanufacturing lead-time. As a consequence we do not have safety stocks for the remanufacturing process, and the stocking point at the remanufacturer can be disregarded. In this way remanufacturable parts travel from stocking point $S_1$ straight to the serviceable stock $S_2$ after a (stochastic) lead-time, which includes transportation and processing time.

- **Manufacturing process.** The serviceable inventory in Kassel ($S_2$) is regularly replenished by the manufacturing of new parts if necessary. The manufacturing lead-time may be stochastic.

- **Disposal process.** As explained before we do not explicitly model the stocks at the remanufacturer. Therefore, disposal of all incoming returned parts occurs if upon arrival the number of remanufacturables in *Kassel* is at a certain prespecified level.

- **Service.** Stockouts occur if a serviceable part is demanded from Kassel (flows $D_1$ and $D_2$), but $S_2$ is out of stock. Every time that this occurs, the demanded part is backordered and a fixed penalty per occurrence is paid.

- **Cost structure.** The cost structure consists of fixed costs per (re-)-manufacturing batch and variable costs per product for (re)manufacturing, holding costs for serviceable inventory and holding costs for remanufacturable inventory, variable disposal costs, and backorder costs per stockout occurrence.

## 8.2 Data specification

Real data was provided by Volkswagen on five remanufacturable parts, which we denote by Engine 1, Loader, Axis joint, Injection pump, and Engine 2. The data concerning lead times are expert guesses. The data was specified as follows:

- **Demand and return process.** The average inter-arrival times in days and the first and second moments of the batch sizes for return flow $R$ and demand flow $D$ are specified in Table 8.1. According to VW Kassel an exponential distribution is a reasonable approximation for both the return and the demand process. For the batch-size distributions we fitted a discrete valued distribution to a continuous lognormal distribution with given mean and variance. All data were derived from real transaction data.

- **Remanufacturing process.** No exact figures for the remanufacturing lead-time were derived. The responsible specialist specified a

| | $R$ flow | | | $D$ flow | | |
|---|---|---|---|---|---|---|
| | average inter-arrival times | batch-sizes | | average inter arrival times | batch-sizes | |
| | | mean | variance | | mean | variance |
| Axis joint | 2.35 | 7.79 | 16.67 | 2.12 | 4.20 | 3.89 |
| Engine 1 | 0.65 | 2.28 | 2.18 | 0.56 | 1.89 | 1.86 |
| Engine 2 | 32.06 | 13.00 | 10.18 | 4.72 | 1.90 | 1.59 |
| Injection pump | 2.18 | 4.81 | 9.51 | 1.26 | 2.83 | 3.60 |
| Loader | 0.66 | 6.79 | 9.37 | 0.47 | 4.44 | 6.45 |

**Table 8.1**. *Average inter-arrival times in days, and mean and variance of batch sizes for the R, and D flow.*

'normal' lead-time of 4–6 weeks. However, if batch size and delivery date vary strongly, the lead-time will increase. For reasons of simplicity we have assumed a uniform lead time distribution on the interval $[28, 42]$ (in days). experiments with other distributions did not lead to significantly different results.

The decision whether a used part is remanufacturable or not is made by a visual inspection at the dealer level. The remanufacturing yield of parts stored in $S_1$ was specified to be 100%, although in reality this percentage may be lower. This however has no consequences for the amount of remanufactured parts that will be delivered by the remanufacturer. The risk of part failure is completely bared by the remanufacturer. On the other hand, Volkswagen has committed themselves to pay a higher price for the remanufactured parts to compensate for the risk of the remanufacturer.

- **Manufacturing process.** Also for the manufacturing lead-time an expert guess of 4–6 weeks was specified and if batch size and delivery date vary strongly, the lead-time will increase. For reasons of simplicity we have assumed a uniform lead time distribution on the interval $[28, 42]$ (in days).

- **Transport.** The lead times corresponding to the transport of remanufacturable parts from Kassel to the remanufacturer were said to be very small compared to the remanufacturing lead-times. Therefore, we assume a zero transportation time.

| | $R$ part | | $P_r$ part | $P_m$ part | | $D$ Part |
|---|---|---|---|---|---|---|
| | cost | sales | cost (approx.) | cost | sales | sales |
| Axis joint | 5 | 2–10 | 153,55 | 200 | 257,50 | 170,00 |
| Engine 1 | 180 | 20–50 | 2243,99 | 2920 | 6366,35 | 3426,30 |
| Engine 2 | 1 | 20–50 | 1058,87 | 1380 | 2245,10 | 1297,20 |
| Injection pump | 15 | 2–10 | 327,00 | 425 | 877,50 | 476,78 |
| Loader | 20 | 2–10 | 334,00 | 434 | 1216,95 | 778,05 |

**Table 8.2**. *Prices (DM) for $R$, $P_r$, $P_m$, and $D$ parts.*

- **Disposal process.** There was no data specified on the disposal process.

- **Cost structure.** Prices of $R$, $P_r$, $P_m$, and $D$ parts are specified in Table 8.2. Column 3 (sales price $R$ parts) refers to the amount of money that will be *received* for the particular part if it is disposed off. In other words, these are disposal *yields*. In general, disposal yields amount to 200–300 DM/ton ('small parts' 2–10 DM/part, engines 20–50 DM/part, catalysts 50 DM/part). In our simulation study we have used the lowerbound of these disposal yields.

  Inventory holding costs are specified as 5% of the cost price p.a. for remanufacturables ($R$ parts) and 18% of the cost price p.a. for serviceables ($D$ parts).

  Ordering costs are 56 DM per order for (re)manufacturing. No costs are associated with transport from Kassel to the remanufacturer.

  Backordering costs in case of a stockout of $D$ parts are calculated as the difference between the sales price of manufactured parts ($P_m$ parts) and the sales price of remanufactured parts ($P_r$ parts). Note that the sales price of $P_m$ parts is only used to handle backorders. The 'real' price for which a manufactured part is sold is the sales price of a $D$ part.

## 8.3 Data analysis

As a first check, we have listed in Table 8.3 the average number of arrivals per day for the return and demand flows of all the part types. These figures were derived by dividing the average batch sizes by the average inter-arrival times (see Table 8.1).

| | $R$ flow | $D$ flow |
|---|---|---|
| Axis joint | 3.31 | 1.98 |
| Engine 1 | 3.51 | 3.38 |
| Engine 2 | 0.41 | 0.40 |
| Injection pump | 2.21 | 2.25 |
| Loader | 10.29 | 9.45 |

**Table 8.3**. *Average number of returns and demands per day.*

| Stage | | demand rate | return rate | Engine 1 | Loader | Axis joint | Inject. pump | Eng. 2 |
|---|---|---|---|---|---|---|---|---|
| **Stage I** | 1 | 25% | 0% | | | | | |
| | 2 | 50% | 0% | | | | | |
| **Stage II** | 3 | 75% | 25% | | | | | |
| | 4 | 100% | 50% | | | | | |
| | 5 | 100% | 75% | | | | | |
| **Stage III** | 6 | 100% | 100% | | | | X | X |
| **Stage IV** | 7 | 75% | 100% | X | X | | X | X |
| | 8 | 50% | 100% | | X | | | |
| | 9 | 25% | 75% | | | X | | |
| **Stage V** | 10 | 0% | 50% | | | | | |
| | 11 | 0% | 25% | | | | | |

**Table 8.4**. *Positioning of the five car parts in the product life-cycle.*

Note that for parts Engine 1, Loader, Axis joint and Engine 2 the average number of returned car parts exceeds the average number of demands. If we would apply the life-cycle framework of Chapter 6, and we assume that at least 80% of the used car parts is being retrieved than the car parts would be positioned more or less as in Table 8.4, i.e., Engine 1 would be near to position 7 (Decline), the Loader somewhere between position 7 and 8 (Decline), the Axis joint near position 9, and the Injection pump and Engine 2 would be between position 6 (Maturity) and 7 (Decline).

As a first cost efficiency check we show in Figure 8.3 the *'direct variable net yield'* of (re)manufacturing for all part types. With this term we denote the yields minus the costs which can be directly associated with an individual (re)manufactured part. For manufacturing this term is calculated as the sales price of a manufactured part minus the cost price of manufacturing; for remanufacturing it is calculated as the sales price of a remanufactured part minus the cost price of remanufacturing minus the cost price of a

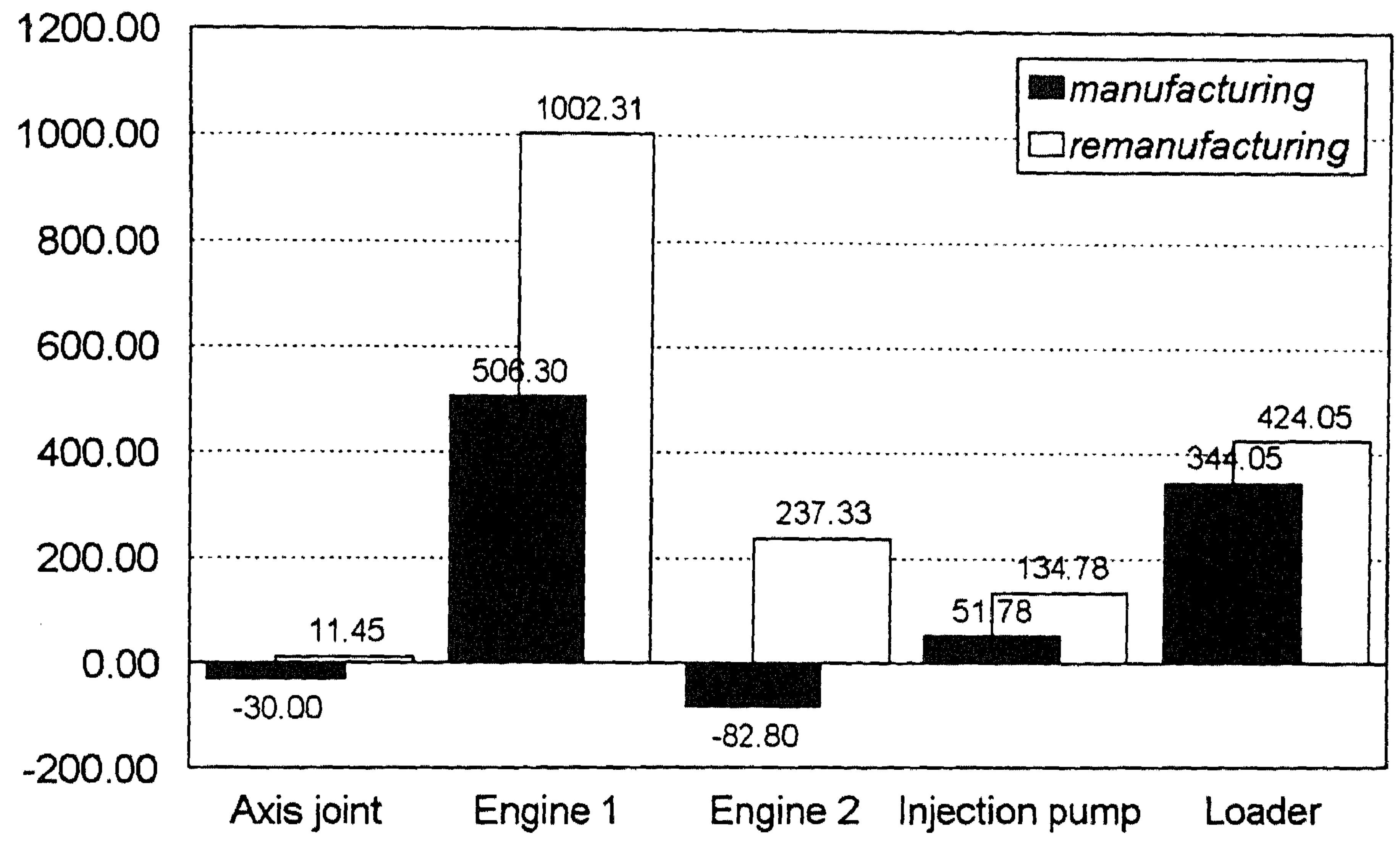


**Figure 8.3.** *Direct variable net yields (DM) for (re)manufacturing.*

remanufacturable part. It must be noted that with respect to the *sales* price there is no difference between a manufactured part and a remanufactured part. However, their cost prices may differ.

Considering Figure 8.3 it may be concluded that for all five part types remanufacturing is cost efficient, although the margins on the Axis joint seem rather low. Manufacturing is not cost efficient in case of the Axis joint and Engine 2, while the margins on the Injection pump are rather low. Of course, in the calculations we have disregarded holding costs, backorder costs, fixed ordering costs for (re)manufacturing, and disposal yields.

**Remark 8.1** *The holding costs for remanufacturable parts are vary small compared to holding costs for serviceables (see Table 8.5). This strongly suggests the use of a PULL strategy instead of a PUSH strategy to control the system. Furthermore, the relatively high backorder costs will impose a high service level on the system.*

To asses the performance of the hybrid manufacturing/remanufacturing system a small simulation study was done, using the data from Section 8.2. Here we treat the data as long-run data and consequently the results are long-run results.

To control the stocking points we define *inventory position* as the total serviceable inventory in Kassel, plus all outstanding orders at the (re)manufacturer, minus the number of backorders. The control policy is a simple

| | **Remanufacturable holding costs** | **Serviceable holding costs** | | **Backorder costs** |
|---|---|---|---|---|
| | | remanufactured parts | manufactured parts | |
| Axis joint | 0,0007 | 0,08 | 0,10 | 87,50 |
| Engine 1 | 0,0243 | 1,11 | 1,44 | 2940,05 |
| Engine 2 | 0,0001 | 0,52 | 0,68 | 947,90 |
| Injection pump | 0,0021 | 0,16 | 0,21 | 400,72 |
| Loader | 0,0027 | 0,16 | 0,21 | 438,90 |

**Table 8.5**. *Comparison between holding costs per day per part, and backorder costs per occurrence per part.*

$(s^-, S)$ PULL policy, i.e., if the inventory position drops to the level $x \leq s^-$ and the inventory of remanufacturables in Kassel contains at least enough parts to increase the inventory position unto $S$, a *transport order* from Kassel to the remanufacturer of $S - x$ remanufacturable parts is initiated. Remanufacturing starts as soon as the batch arrives at the remanufacturer. This ordering policy minimizes the inventory at the remanufacturer, while it is also cost efficient due to the very short lead-time of the transport. An additional advantage is that Kassel keeps maximal control of its stocks. The latter may be important in case of planned disposals.

If the inventory position has dropped to the level $x \leq s^-$ and the inventory of remanufacturables in Kassel does not contain enough parts to increase the inventory position unto $S$, a manufacturing order of size $S - x$ is placed. Incoming batches of returned parts are disposed of, if the inventory of remanufacturable parts in Kassel equals or exceeds the level $s_d$. The strategy parameters are optimized by a grid search procedure, i.e., an incomplete enumeration over $s$ and $S - s^-$ finds the (near) optimal strategy. For now, we have set the disposal level relatively high to minimize the number of disposals. The value of the disposal level is *not* being optimized.

The results of Table 8.6 show the PULL character of the control policy in the average levels of the inventories: serviceable inventory levels are much lower than remanufacturable inventory levels. Furthermore, all five instances are characterized by very high service levels. This is due to the fact that backorder costs are relatively high. Figure 8.4 shows that for all car parts the biggest share of total cost is taken by the serviceable inventory

| | Control parameters | | Statistics | | | |
|---|---|---|---|---|---|---|
| | $s^-$ | $S$ | Average net yields (DM per day) | Average serviceable inventory | Average remanufact. inventory | Average service level (%) |
| Axis joint | 110 | 175 | 16,23 | 75 | 1180 | 99.4 |
| Engine 1 | 190 | 205 | 3290,92 | 80 | 314 | 100.0 |
| Engine 2 | 30 | 45 | 74,28 | 25 | 857 | 99.5 |
| Inj. pump | 135 | 175 | 284,86 | 77 | 357 | 99.8 |
| Loader | 500 | 620 | 3979,28 | 230 | 1073 | 100.0 |

**Table 8.6**. *Optimal solution and associated statistics obtained by simulation.*

costs (between 61 and 82%). In spite of the high levels of remanufacturable inventory, its cost share is far less than that of serviceable inventory. Total setup costs comprise between 10 and 18% of total costs.

To investigate the cost-efficiency of the HMR system we divide the optimal average yields per day (4th column of Table 8.3) by the average number of demands per day (3rd column of Table 8.1). In accordance with Figure 8.3, Figure 8.5 shows that Engine 1 and the Loader are the most cost-efficient parts, while the margins on the Axis joint are rather low.

## 8.4 System behaviour during a product life-cycle

To investigate the behaviour of the HMR system during the complete product life-cycle we use the data of Engine 1 and construct the following scenario. Notice first that Engine 1 is positioned somewhere at the beginning of the decline stage (see Table 8.4). If we assume an average recovery rate of 80% then it is reasonable to associate the return and demand rate of table 8.3 with position 7 and we can extrapolate the data to all other positions. In this way we arrive at the scenario in Table 8.7.

Similar to Section 6.3 we can compute for all the return and demand rate combinations of Table 8.7 the optimal long-run average costs and yields per day. This will give us a reasonable idea about the system behaviour with respect to costs, yields and control parameters. The simulation results are listed in Table 8.8.

The main result that we can draw from this example is that it is very important to regularly revise the reorder level $s^-$. Also it is important to determine its values accurately, since the largest share of total costs is due to serviceable inventory costs. Moreover, backorders are costly. The

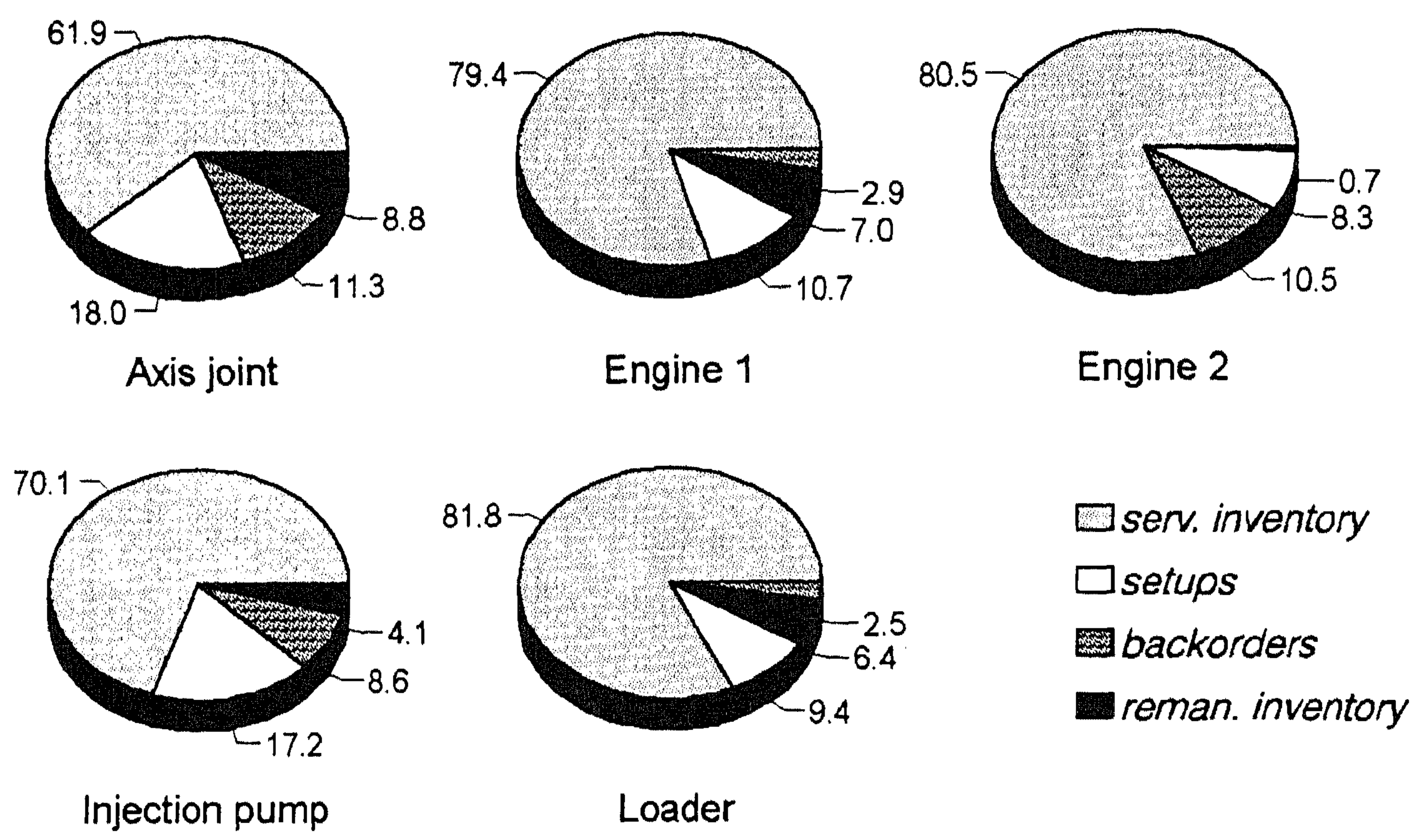


**Figure 8.4.** *Cost shares (%) of costs related to inventories, setups and backorders, associated with the optimal solution obtained by simulation.*

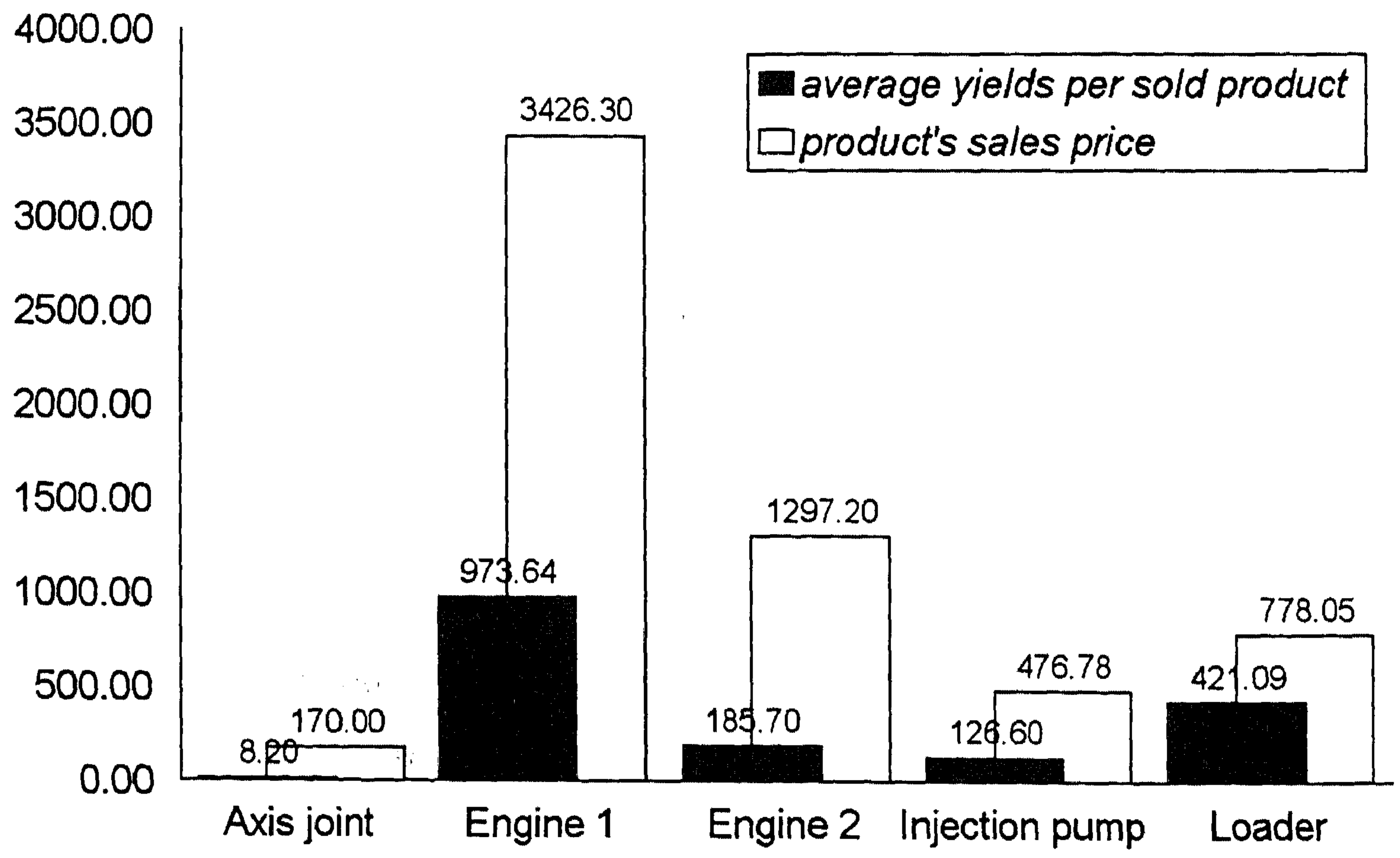


**Figure 8.5.** *Average yields (DM) per product sold under the optimal policy obtained by simulation, compared with the sales price.*

| Stage | | demand rate | return rate |
|---|---|---|---|
| **Stage I** | 1 | 1.13 | 0 |
| | 2 | 2.25 | 0 |
| **Stage II** | 3 | 3.38 | 0.88 |
| | 4 | 4.51 | 1.76 |
| | 5 | 4.51 | 2.63 |
| **Stage III** | 6 | 4.51 | 3.51 |
| **Stage IV** | 7 | 3.38 | 3.51 |
| | 8 | 2.25 | 3.51 |
| | 9 | 1.13 | 2.63 |
| **Stage V** | 10 | 0 | 1.76 |
| | 11 | 0 | 0.88 |

**Table 8.7**. *Life-cycle scenario for Engine 1, obtained by extrapolating the original data (position 7), while assuming an average recovery rate of 80%.*

| Stage | | demand rate | return rate | $s^-$ | $S - s^-$ | $s_d$ | Average yields |
|---|---|---|---|---|---|---|---|
| **Stage I** | 1 | 1.13 | 0 | 70 | 25 | – | 499.30 |
| | 2 | 2.25 | 0 | 130 | 15 | – | 1038.47 |
| **Stage II** | 3 | 3.38 | 0.88 | 180 | 20 | 50 | 2050.20 |
| | 4 | 4.51 | 1.76 | 230 | 15 | 100 | 3030.06 |
| | 5 | 4.51 | 2.63 | 240 | 20 | 100 | 4321.95 |
| **Stage III** | 6 | 4.51 | 3.51 | 240 | 30 | 150 | 3906.40 |
| **Stage IV** | 7 | 3.38 | 3.51 | 180 | 25 | 250 | 3297.61 |
| | 8 | 2.25 | 3.51 | 130 | 20 | 250 | 2200.46 |
| | 9 | 1.13 | 2.63 | 70 | 25 | 50 | 1107.52 |
| **Stage V** | 10 | 0 | 1.76 | – | – | 0 | 35.20 |
| | 11 | 0 | 0.88 | – | – | 0 | 17.60 |

**Table 8.8**. *Optimal long-run yields (DM) per day and associated control variables during the complete product life-cycle of Engine 1.*

optimal reorder quantity $Q$ however does not vary much over time. Further simulation experiments showed that the costs were not particularly sensitive to a change in the value of $Q$. The disposal level $s_d$ does not play an important role here, since remanufacturable inventory is valued very low and disposal yields are nothing compared to the remanufacturing yields. The best thing to do therefore is to dispose as least as possible.

## 8.5 A simple heuristical procedure

Volkswagen Kassel was particularly interested to investigate whether a simple heuristical procedure could generate (near) optimal strategies. The procedures that were developed in the previous chapter are not useful here, since they only apply to PUSH type policies, and a netting approach was seen to be unappropriate.

As an alternative we develop a simple heuristic which makes use of some specific characteristics of the HMR system in Kassel. Our approach is to combine an adaptation of the standard EOQ formula with a simple $s^-$ rule:

I Compute $S - s^-$ according to the standard EOQ formula,i.e.,

$$S - s^- := \sqrt{\frac{c_f \lambda_D}{h}},$$

where

$$h = \begin{cases} \frac{\lambda_D h_s^m + (\lambda_D - \lambda_R) h_s^r}{\lambda_D}, & \lambda_R \leq \lambda_D, \\ h_s^r, & \lambda_R > \lambda_D, \end{cases}$$

and $\lambda_D$ is the demand rate, $\lambda_R$ is the return rate, $c_f$ is the fixed cost of (re)manufacturing, and $h_s^m$ and $h_s^r$ are the serviceable holding cost for manufactured and remanufactured products respectively.

II Next, we use a simple and fast numerical procedure to compute $s^-$ under a service level constraint (see Tijms [56], page 68–69). This procedure takes into account the first and second moments of the demand batch sizes, and the (re)manufacturing lead-time.

| | Control parameters | | Statistics | | | |
|---|---|---|---|---|---|---|
| | $s^-$ | $S$ | Average net yields (DM per day) | Average serviceable inventory | Average remanufact. inventory | Average service level (%) |
| Axis joint | 127 | 180 | 15,92 | 84 | 1182 | 99.9 |
| Engine 1 | 179 | 197 | 3291,79 | 70 | 312 | 99.8 |
| Engine 2 | 36 | 45 | 72,25 | 28 | 952 | 99.8 |
| Inj. pump | 133 | 173 | 280,61 | 75 | 253 | 99.8 |
| Loader | 471 | 552 | 3974,68 | 181 | 1095 | 99.7 |

**Table 8.9**. *Optimal solution obtained by a simple $(s^-, S)$ rule, under a service level constraint of* 99.9%. *The associated statistics were obtained by simulation.*

In fact what we do in the above procedure is the following: we treat the hybrid manufacturing/remanufacturing system as a classical single source inventory problem. This assumption is reasonable because *(i)* the manufacturing process and the remanufacturing process are equal with respect to lead-times, fixed setup costs, and reorder level *(ii)* remanufacturable inventory is valued very low, so disregarding this factor is expected to have a limited influence on the optimal solution, and *(iii)* disposals occur only if the return rate exceeds the demand rate; in this case the disposal rate is approximately equal to the return rate minus the demand rate.

Table 8.9 shows that the performance of the heuristical approach is quite satisfactory for all five examples (compare with table 8.6). If the same system conditions hold for the complete product life-cycle we would expect that this approach also should work for other demand and return rate combinations. Table 8.10 indeed shows that this is the case for Engine 1 (compare with table 8.8).

However, as a consequence of our assumptions, this approach will probably fail in a situation in which there will be more interaction between the manufacturing process and the remanufacturing process, and/or a situation in which the characteristics of the manufacturing process differ considerably from the characteristics of the remanufacturing process, or a situation in which a PUSH strategy is more appropriate.

## 8.6 Summary and conclusions

In this chapter we investigated an example of product remanufacturing in practice: the remanufacturing of car parts at Volkswagen, Kassel in Ger-

| Stage | | demand rate | return rate | $s^-$ | $S - s^-$ | Average yields heuristic | grid search |
|---|---|---|---|---|---|---|---|
| **Stage I** | 1 | 1.13 | 0 | 76 | 7 | | 499.30 |
| | 2 | 2.25 | 0 | 130 | 10 | | 1038.47 |
| **Stage II** | 3 | 3.38 | 0.88 | 181 | 13 | | 2050.20 |
| | 4 | 4.51 | 1.76 | 232 | 15 | | 3030.06 |
| | 5 | 4.51 | 2.63 | 232 | 16 | | 4321.95 |
| **Stage III** | 6 | 4.51 | 3.51 | 231 | 17 | | 3906.40 |
| **Stage IV** | 7 | 3.38 | 3.51 | 179 | 18 | | 3297.61 |
| | 8 | 2.25 | 3.51 | 128 | 15 | | 2200.46 |
| | 9 | 1.13 | 2.63 | 75 | 11 | | 1107.52 |
| **Stage V** | 10 | 0 | 1.76 | – | – | | 35.20 |
| | 11 | 0 | 0.88 | – | – | | 17.60 |

**Table 8.10**. *Long-run yields (DM) per day and associated control variables, resulting from the heuristical approach, during the complete product life-cycle of Engine 1.*

many. Real transaction data was used to build a simulation model of the HMR system with remanufacturing. Since both the manufacturing and remanufacturing process can be viewed as external processes, a simple single-echelon model without (dis)assembly can give a relatively good description of the actual situation.

The main result of the small simulation study is that the HMR system at Volkswagen AG in Kassel can be controlled in a cost-efficient way by a simple reorder $(s^-, S)$ policy. The manufacturing and remanufacturing process are very similar with respect to lead times and fixed ordering costs, and disposal only plays a minor role, since remanufacturable holding costs are minimal. These conditions allow for a simple policy as long as the control parameters are regularly revised throughout the product life-cycle. Under the same conditions it is possible to use a simple heuristical procedure to compute reasonable values for the control parameters.