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Assessment of products' reliability influence on remanufacturing processes

Keywords

remanufacturing, returned products quantity, return reasons, reliability models for returns quantity predicting

Abstract

Remanufacturing is a process of recapturing value from returned products. Whole products are brought back to like-new condition. The seven factors, that make production planning and process control for remanufacturing more complicated then equivalent activities in normal manufacturing, had been proposed in literature. The main one is the uncertain timing and quantity of returns. There is a lack of reliability based forecasting models to better predict products life-cycles, return rates and quantities. Only one reliability based production planning method for remanufacturing had been proposed. It identifies two return reasons and it is appropriate only for single-use products. In practice most of products are serviced and return only in specific cases. In this article seven different return reasons has been identified and third one has been investigated. Other will be studied in future papers.

1. Introduction

Remanufacturing is a process of recapturing value from returned products. Whole products are brought back to like-new condition. First part of the process is disassembly of product, then parts are restored or replaced and product is reassembled. Returned product never goes back to the place where it was returned from. The seven factors that make production planning and process control for remanufacturing more complicated then equivalent activities in normal manufacturing had been proposed in literature:

1. the uncertain timing and quantity of returns;
2. need to balance returns with demands;
3. the disassembly of returned products;
4. the uncertainty in materials recovered from returns;
5. the requirement for reverse logistics network;
6. material matching restriction;
7. stochastic routing for materials and variable processing times.

In the same article in research issues author placed the need to create reliability based forecasting models to better predict products life-cycles, return rates and quantities. Since that time only one reliability based production planning method for remanufacturing has been proposed. [1]-[5].

2. Existing prediction method

In this method product is composed of components $C_1, C_2, \ldots, C_n$. Product cannot work if any of components fails. There are several assumptions in this method:

1. each component failure is independent;
2. component is reusable if its residual life surpasses a threshold value, tr;
3. product is returned (its life is ended) because of:
   a. any component failure;
   b. a user comes to regard the product as worthless and disposes it though it can work. It is called "the time to losing value";
   c. more than two of physical failures and losing value never occur simultaneously.

This method is helpful in assessing the quantity of returned products to be disassembled and quantity of reusable components. The probability that the life of a product purchased at time t is ended in the interval between t_a and t_b, is described by:

$$P_{ta \to tb}(t) = \int_{ta-t}^{tb-t} h(x)dx \,, \tag{1}$$

Where $h(x)$ is probability density function of ending the life for the product. It includes probability that the product is returned because of losing value and probability that the life of the product is ended by the physical failure of any component. Where $v(x)$ is the probability density function of the time to losing value. $f_k(x)$, k=1,2,…,n is a probability density function of the time to physical failure of component C_k.

$$h(x) = v(x) \cdot \prod_{j=1}^{n} \left(1 - \int_0^x f_j(t)dt\right) +$$

$$+ \sum_{k=1}^{n} \left\{ f_k(x) \cdot \left(1 - \int_0^x v(t)dt\right) \cdot \prod_{(j:\, j \in N,\, j \neq k)} \left(1 - \int_0^x f_j(t)dt\right) \right\}, \quad (2)$$

If the density function of demand g(t) is known it is possible to predict the quantity of returned products between t_a and t_b:

$$PN_{ta \to tb} = \int_0^{ta} g(t) \cdot P_{ta \to tb}(t)dt, \quad (3)$$

Component included in returned product is reusable if it hasn't failed in analysed time unit x (product ended its life but not because this component failure) and can work for more than $x+tr$. For more information see [4]-[6].

3. Proposed development of existing model

In presented method every failure means that product is returned but it is true only for single-use products. In practice most of failed products are serviced and only a specific part of this stream is treated as return. Products are also returned from different parts of supply chain in various quantity and timing. In practice it is possible to identify at least seven product return reasons [7].

1. Products that never leave factory because of failed quality tests, defective components and production process unreliability.
2. Physical failure of product during transportation process.
3. Physical failure of product that occur in first 3-4 weeks from purchasing by the final user.
4. Products serviced second or third (it depends on company politics) time during first year of warranty.
5. Products that were serviced and there were no spare parts in service inventory and delay between request and resupply was longer then two weeks.
6. If product cannot be repaired or repair costs are very high. It is because of critical component failure or great quantity of failed components.
7. After warranty period when a user comes to regard the product as worthless and disposes it though it can work. It is called "the time to losing value".

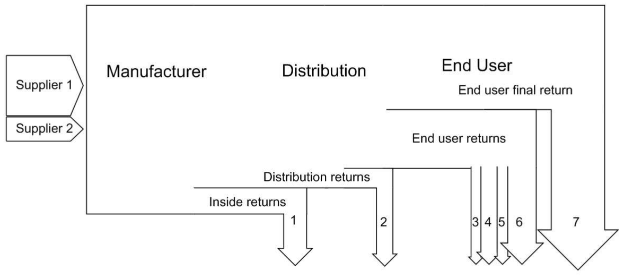

Figure 1. Seven reasons of product return and return sources

In this article third return reason is investigated. Other will be studied in future papers. Products can be return only if failures occur in specific time period from purchasing. Length of this period is described by t_1. We cannot take into consideration products that had been sold earlier than t_a-t_1. $t+t_1$ it is something like upper bound on return time. This method is helpful in predicting the quantity of these specific products purchased at time t and returned between t_a and t_b. It is important to know if time between t_a and t_b is longer than t_1. That is why it is necessary to investigate two different cases when:

$$t_b - t_a < t_1, \quad (4)$$

and

$$t_b - t_a \geq t_1. \quad (5)$$

Probability of product failure because of any component failure between x_1 and x_2 is described by:

$$w(x_1, x_2) = \left(1 - \prod_{j=1}^{n} \left(1 - \int_{x_1}^{x_2} f_j(t)dt\right)\right). \quad (6)$$

For equation (4) quantity of returned products between time period t_a and t_b can be described by:

$$PN_{t_a \to t_b} = PN_{1_{t_a \to t_b}} + PN_{2_{t_a \to t_b}} + PN_{3_{t_a \to t_b}}, \quad (7)$$

where:

$$PN_{1_{t_a \to t_b}} = \int_{t_a - t_1}^{t_b - t_1} g(t) \cdot w(t_a - t, t_1)dt, \quad (8)$$

$$PN_{2_{t_a \to t_b}} = \int_{t_b - t_1}^{t_a} g(t) \cdot w(t_a - t, t_b - t)dt, \quad (9)$$

$$PN_{3_{t_a \to t_b}} = \int_{t_a}^{t_b} g(t) \cdot w(0, t_b - t) dt \,. \qquad (10)$$

For equation (5) quantity of returned products between time period t_a and t_b can be described by:

$$PN_{t_a \to t_b} = PN_{1_{t_a \to t_b}} + PN_{2_{t_a \to t_b}} + PN_{3_{t_a \to t_b}} \,, \qquad (11)$$

where:

$$PN_{1_{t_a \to t_b}} = \int_{t_a - t_1}^{t_a} g(t) \cdot w(t_a - t, t_1) dt \,, \qquad (12)$$

$$PN_{2_{t_a \to t_b}} = \int_{t_b - t_1}^{t_b} g(t) \cdot w(0, t_b - t) dt \,, \qquad (13)$$

$$PN_{3_{t_a \to t_b}} = \int_{t_a}^{t_b - t_1} g(t) \cdot w(0, t_1) dt \,. \qquad (14)$$

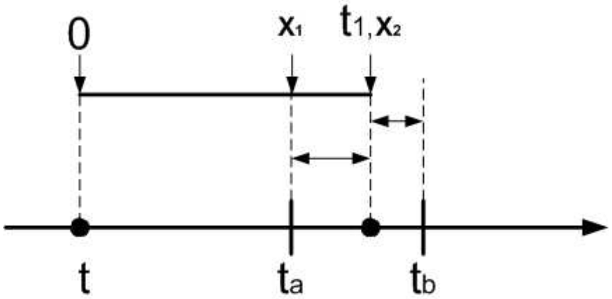

Figure 2. Predicted quantity of returned products between t_a and t_b described by equation (8)

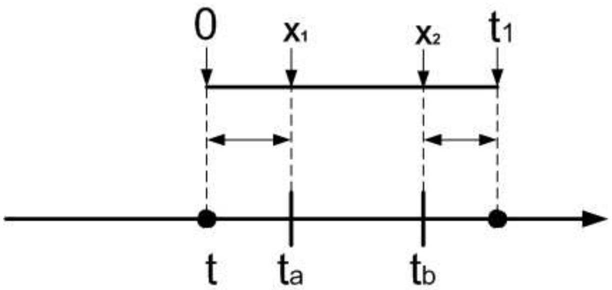

Figure 3. Predicted quantity of returned products between t_a and t_b described by equation (9)

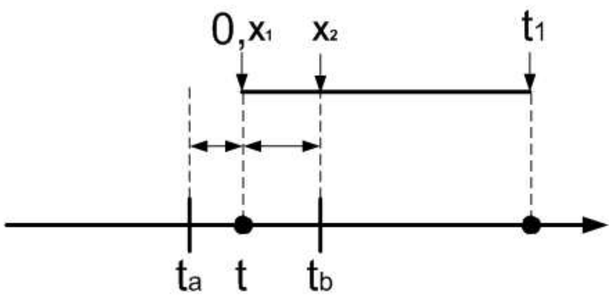

Figure 4. Predicted quantity of returned products between t_a and t_b described by equation (10)

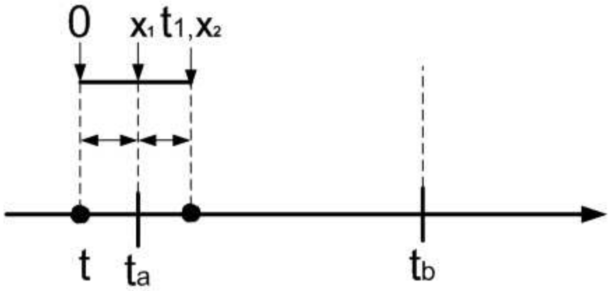

Figure 5. Predicted quantity of returned products between t_a and t_b described by equation (12)

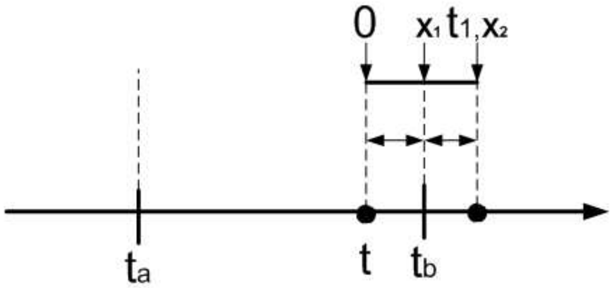

Figure 6. Predicted quantity of returned products between t_a and t_b described by equation (13)

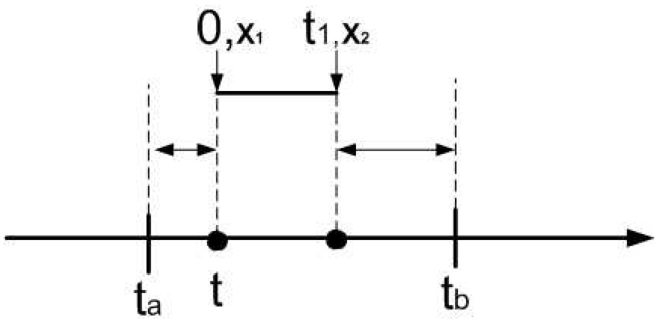

Figure 7. Predicted quantity of returned products between t_a and t_b described by equation (14)

4. Modeled situation

In this paper Monte Carlo simulation of third reverse flow was made. Analysed data were collected from existing system from products sold in February 2007. There are four employees in existing system. Company wants to know if it is cost-effective to invest in remanufacturing process. Now only a small part of failed products came back and all returned products are processed. In future it is possible to create main remanufacture centre and probably there will be a need to employ more workers. The goal of this simulation is to show system behaviour during one year if there would be much more product returns than presently.

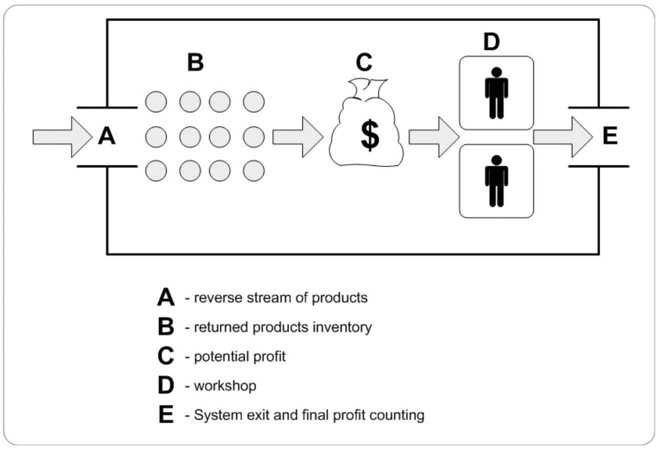

Figure 8. Modeled remanufacture system

4.1. Assumptions

In modeled situation returns came back if product failure occur in first four weeks from purchasing by the end user. Products are sold in quantity 200000 at the beginning of each *m* analysed time periods. Additionally:

$$t_b - t_a = t_1, \tag{15}$$

and

$$t = t_a. \tag{16}$$

Products may return simultaneously. Time to failure is described by Weibull probability distribution function with shape parameter α=1,46 and scale parameter β =0,0096. Returned products are stored. Every returned product can be remanufactured. After remanufacturing returned products there is no need to produce new ones. There are *k* employees working in workshop. One product can be remanufactured only by one employer. Next returned product is remanufactured by first free employer. Repair time is random value and it is described by Lognormal probability distribution function. Not remanufactured products are stored and remanufactured at the beginning of next time period. Mean value of periodical profit is a main system effectiveness measure. Periodical profit is described by:

$$PP_i = RP_i \cdot PV - LC \cdot k - NRP_i \cdot SC - TC \cdot RQ_i, \tag{17}$$

where:

$NRP_i = NRP_{i-1} + RQ_i - RP_i$, i=1,2,…,m - not remanufactured products quantity [pieces],
PP_i - periodical profit [PLN/time period],
RP_i - remanufactured products quantity [pieces/time period],
PV - product value [PLN],
LC - labor costs [PLN/person/time period],
SC - stocking costs [PLN/product/ time period],
TC - transport costs [PLN/product],
RQ_i - returned products quantity [pieces/time period].

In simulated situation:
PV - 2100 [PLN/product],
LC - 3500 [PLN/person],
SC - 10,5 [PLN/product/ time period],
TC - 70 [PLN/product].

This simulation can be helpful in decision making process especially in answering if organizing the remanufacturing process in own company is cost-effective. It is if reached profit is lower than purchase price offered by third-party providers, which is 30% of new product value. It can also tell how many employees should the company have.

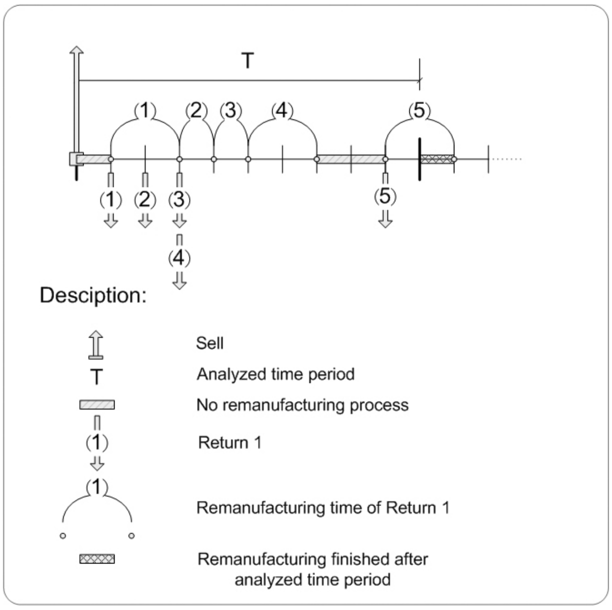

Figure 9. Modeled remanufacture system single employee case

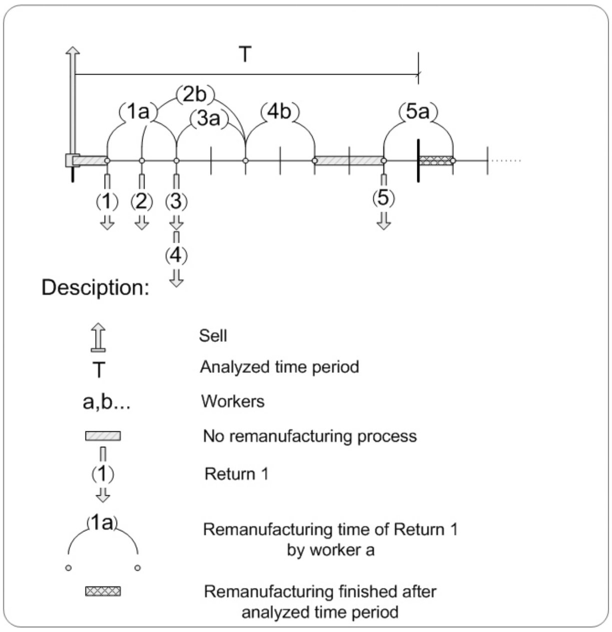

Figure 10. Modeled remanufacture system multi employee case

4.2. Simulation results

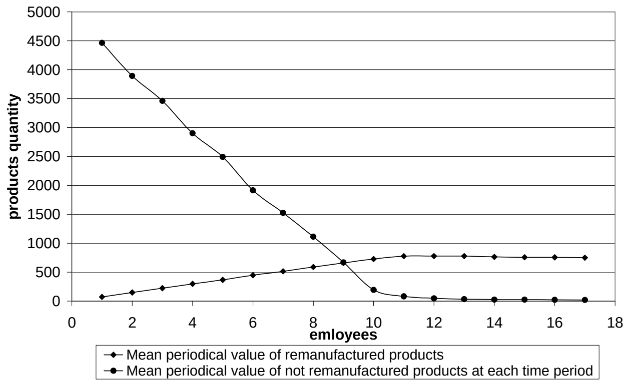

Figure 11. Simulation results

Figure 11 presents the change of mean periodical value of remanufactured and not remanufactured products. Mean periodical value of not remanufactured products has been decreased by increase of employees quantity. It can be seen that there is no significant change of remanufactured products level from twelve employees. Also mean profit value stops increasing from twelve employees and thirteen employees drag it down, see *Figure 12*. At twelve employees level mean periodical net profit approaches to potential mean periodical net profit. In *Figure 12* it can also be seen that, at this level of returns and costs, for three employees mean profit is lower than third-party provider offer. But it is cost-effective with four workers. For *SC*=105 [PLN] situation will change, see *Figure 13* and *Figure 14* shows the change of inventory level at the end of each time period caused by increased level of employment.

In sum at this returns and costs level optimal situation is to employ twelve employees because it maximize mean profit value.

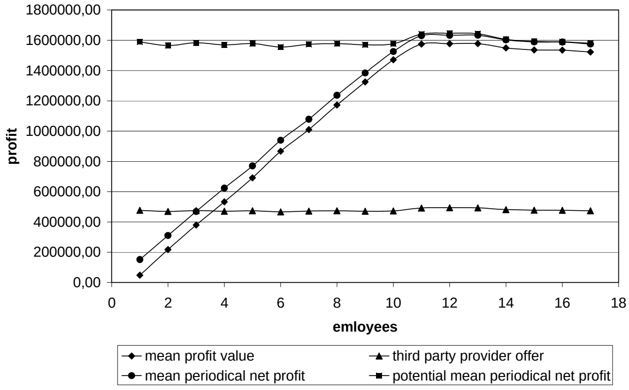

Figure 12. Simulation results

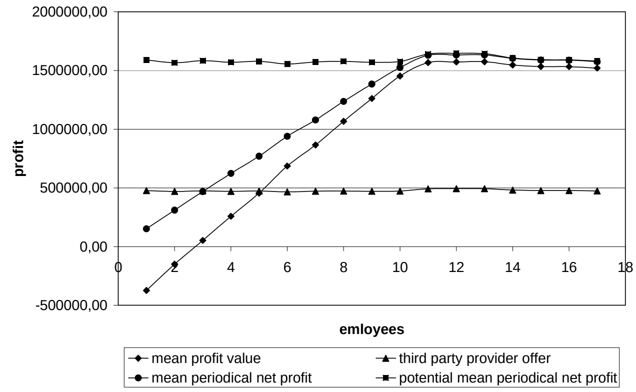

Figure 13. Simulation results for higher stocking costs

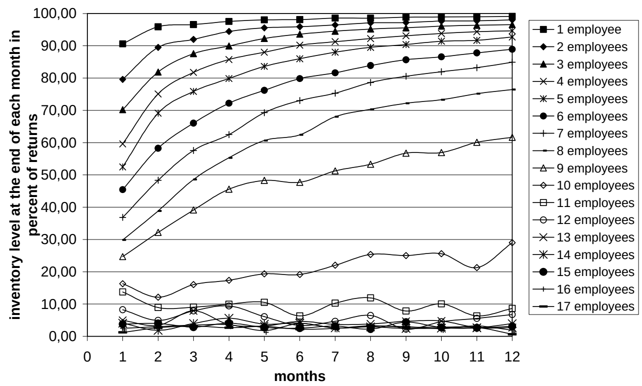

Figure 14. Simulation results

5. Conclusion

There is a lack of reliability based forecasting models to better predict products life-cycles, return rates and quantities. Only one reliability based production planning method for remanufacturing had been proposed in literature. It identifies only two return reasons and it is appropriate only for single-use products. In practice most of products are services and return only in specific cases. In this article seven different return reasons has been identified and third one has been investigated. Other will be studied in future papers.

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