ABOUT OPTIMAL REMANUFACTURING POLICIES AND SECONDARY MARKETS SUPPLYING

M. Gallo[(a)], L. Guerra[(a)], G. Guizzi[(a)]

(a) Department of Materials Engineering and Operations Management University of Naples "Federico II" - ITALY

'mose.gallo@unina.it' 'luigi.guerra@unina.it' 'g.guizzi@unina.it'

ABSTRACT

The synergic action of different actors involved in environmental protection, is pushing more and more companies to adapt and, in some cases, to revolutionize their strategies, plans and their business goals in an "*environmentally conscious*" way. It is crucial, therefore, to develop and adopt suitable production techniques and EOL management policies for products.

Product recovery involves concepts like reuse, remanufacturing and recycling. In many cases, moreover, reuse and remanufacturing could be simultaneously implemented if *secondary market* supplying is a profitable option. When hybrid remanufacturing/manufacturing systems (HRMSs) are implemented and when secondary markets are supplied with *high quality* returns, some new issues have to be faced and these systems have to be deeply analyzed to better manage them. With this aim three different policies to supply a secondary market will be compared (two *PUSH* policies and one PULL policy), which are based upon different stock level control.

Keywords: tactical analysis, remanufacturing, secondary markets, simulation

1. INTRODUCTION

The increasing rate of products' technological innovation is pushing towards new profit models, based on an integrated management of product life cycle. Innovative policies intended to the recovery of *end of life products*, in fact, not only improve the efficiency in natural resources consumption, but also open new business opportunities for producers (Gungor and Gupta 1999). Among the different recovery options, remanufacturing is of particular importance and is worthwhile of interest (Srivastava and Srivastava 2006).

The aim of this work is to investigate the multifaceted field of remanufacturing and to identify those factors make it a sustainable business from a financial point of view.

The operating cost of a remanufacturing system, in fact, is strictly linked both to strategic decisions (logistics network configuration, secondary markets opportunities, prices of new and remanufactured products, design of new generation products) and to tactical and operational decisions (Daniel, Teunter, and van Wassenhove 2003).

Products at the end of their life cycle can be recovered in many ways and with different levels of efficiency.

The option of materials recycling is at the lowest level of recovery efficiency, this process allows to retrieve the raw material but not the added value of the product.

Higher added-value recovery options are: reconditioning, remanufacturing or cannibalization, where are retrieved, respectively, products, modules or components. Recovery options like repair or reuse don't involve massive restoring activities (Thierry, Salomon, Van Nunen, and Van Wassenhove 1995).

The simultaneous presence of returns with a high residual value and demand for such products on secondary markets, puts the management in front of the dilemma to allocate these units to the secondary market rather than to remanufacture them and supply the primary market.

In an our previous analysis (Gallo, Guerra, and Guizzi 2009) we have assessed the convenience of supplying a secondary market considering some factors related to reverse logistics system (r), to the product (*quality mix*) and to the market (*price*). Being such factors external to the system, the analysis has to be considered from a "strategic" point of view. If supplying a secondary market is a profitable option, the production system has to be reorganized in order to best manage this new demand, determining the most suitable operating rules to be used. To this aim three stock level control strategies for secondary market supplying will be compared: the first two are based upon a PUSH logic and the last upon a PULL logic.

This paper is organized as follows. In the problem setting section the stock level control strategies and the logical model used are presented. In Section 3 some issues about the comparison of the different policies are discussed and the results are presented. Section 4 summarizes our findings and draw the conclusions.

2. PROBLEM SETTING

Many studies confirm that the increased uncertainty and variability in a remanufacturing system makes problematic the use of traditional tools for production planning and control (Guide, Jayaraman, and Srivastava 1999; Guide, 2000).

An important difference between the production planning in traditional systems and in remanufacturing systems is that in the latter disappear the typical hierarchical relationship between the canonical stages of production planning.

The actual production volume, in fact, besides being dependent on market demand and production capacity constraints, depends also on the amount of materials (core, parts and components recovered, new components) that become available or necessary during the production process.

Hence, a proper production planning and control in remanufacturing systems (capacity planning, scheduling, monitoring the progress of orders, etc.) is strongly influenced by a sound planning and control of the recovered materials.

In remanufacturing systems a number of randomness related to the quantity, quality and timing of products or components recoverable, makes the definition of a good stock control policy more difficult (Fleischmann, Kuik, and Dekker 2002).

In Hybrid Manufacturing/Remanufacturing Systems literature comparisons between PUSH and PULL policies are usually performed but such policies typically control manufacturing orders release (Mahadevan, Pyke, and Fleischmann 2003).

In particular adopting the PUSH policy all returns are remanufactured as soon as possible (as soon as a batch of returns is available), while in the PULL policy returns are remanufactured as late as possible (remanufacturable returns are hold until the stock level of the finished product warehouse drops below a specific value).

All things considered, the choice is between remanufacturing or retain a core stock and then remanufacture them later. In these cases, the adoption of a PULL policy is due to the core holding cost increase as remanufacturing process flows by: it could be desirable retaining cores in the upstream warehouses to cut holding costs. In this way finished products stock is reduced but delays and stock out risk increases. Some interesting results are proposed by van Deer Laan, Salomon, Dekker and van Wassenhove (1999): as the difference between cores and finished products holding costs increases, the PULL strategy becomes more and more attractive. If these costs are equal (an unrealistic assumption) is better to use a PUSH strategy.

2.1. Stock level control strategies

In the following analysis the performances of three different stock level control strategies for secondary market supplying will be compared, namely: *PUSH* policy, *PUSH 2* policy and *PULL* policy.

In particular, the *PUSH* policy optimizes, in a specific time horizon, the percentage of high quality returns with which the secondary market will be supplied. This policy doesn't consider the warehouses' stock level in the system when an high quality return occurs, but, it pushes the product, with a certain probability (K_{PUSH}), or into the warehouse specifically intended for secondary market supplying or into the remanufacturing process.

The *PUSH 2* policy works like a disposal policy for returns in excess. A maximum value (K_2) for high quality returns (buffer 2) is defined and when it is exceed products are moved into the warehouse for secondary market supplying. So, without considering the other stock levels, the system pushes the high quality returns which exceed the above mentioned upper limit.

In the *PULL* policy, when an high quality return occurs, a control on the finished product stock level is carried out. Until this level is less than a specific threshold (K_{PULL}) the product is remanufactured, otherwise it is sold on the secondary market.

The product is "pulled" by the finished product warehouse intended for primary market supplying. K_{PUSH} and K_{PULL} values are considered for optimizing the objective function which will be conceived as a profit function taking into account both secondary market supplying opportunities and backorders or delayed orders on the primary market.

2.2. Logical model

We have considered the same multi stage inventory control model used in Gallo, Guerra and Guizzi (2009), but some features of the secondary market and the cost structure are quite different (fig.1).

Even though the secondary market on average is able to absorb the share of high-quality products not used by the primary market (working hypothesis in Gallo, Guerra, and Guizzi 2009)), it is necessary, in this case, to model the secondary market demand, taking into account the time between two subsequent requests in the secondary market.

We introduced, therefore, in the model a warehouse of high quality returns for the secondary market in order to meet demand from such market when it occurs. Such demand is modelled by a Poisson process with parameter $\gamma_{SM} = k_1 * r * \gamma$ (see Gallo, Guerra, and Guizzi 2009 for more details). Being such value the overall high quality returns fraction, on average the secondary market could be able to absorb all high quality returns.

The holding costs for the secondary market buffer are calculated using the "traditional method" (Teunter, van Deer Laan, and Inderfurth 2000).

Unlike the primary market, we don't consider backordered or lost sales on the secondary market.

Moreover to evaluate the effectiveness of the different policies considered, the holding costs are "amplified" in such a way their influence on overall costs is about 15% on average. This increase, in fact, makes more evident the impact of the control policies on the system operation.

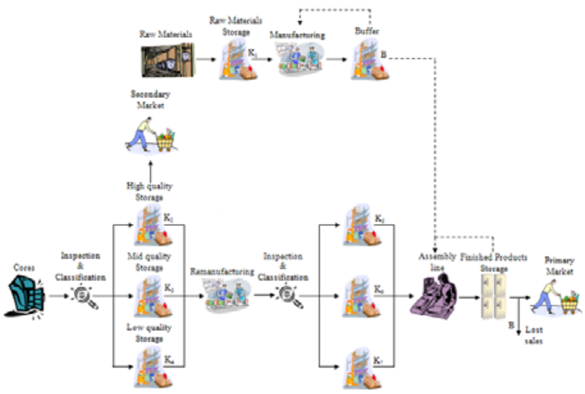


Figure 1 - Multi stage inventory control model with a secondary market

3. RESULTS AND DISCUSSION

3.1. Priority rules performance comparison for PUSH 2 strategy

The performance of the *PUSH 2* control policy is affected by the specific priority rule adopted in the remanufacturing process.

In particular, the remanufacturing process is fed by three different buffers containing high, medium and low quality cores and the choice about the first among these type of core to be remanufactured affects the way the secondary market is supplied with respect to:

- the number of units received in the warehouse intended for secondary market supplying;
- the time between two subsequent sales in the secondary market.

Therefore, to effectively compare the above mentioned policies performance, it is required to carefully choose among the various priority rules the one that allows the *PUSH 2* control policy to work as efficiently as possible.

As concern returns management policies comparison, for the *PUSH 2* policy, the priority rule which best performs according to return rate changes will be considered (Table 1).

Table 1: Adopted Priority Rule for PUSH 2 Policy

Return Rate	Priority Rule
0,7	2, 1, 3
0,8	2, 1, 3
0,9	2, 3, 1

3.2. Secondary market supplying policies performance comparison

Figure 2 summarizes the results obtained comparing the different secondary market supplying policies considered.

The *PULL* policy is the best one, while the *PUSH* policy performs the worst.

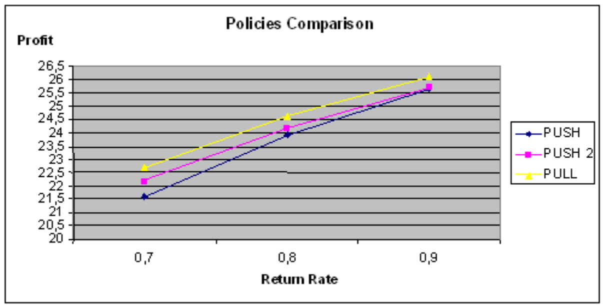
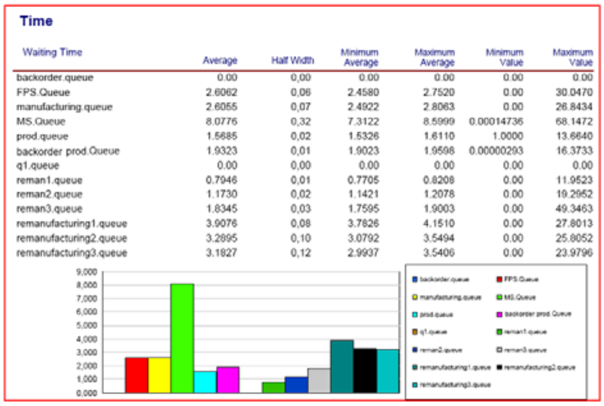


Figure 2: Policies Performance Comparison

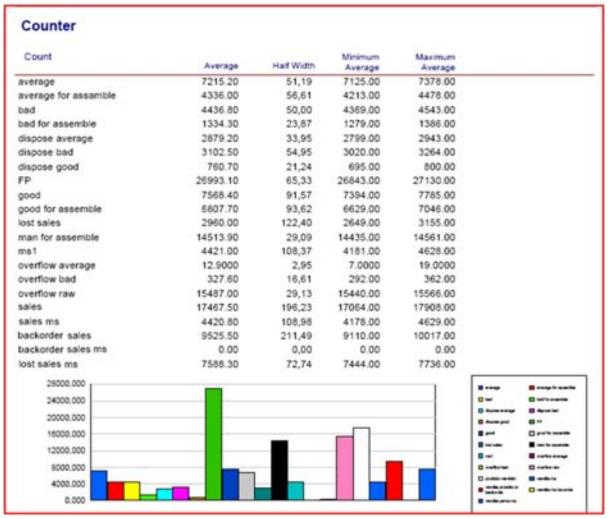
Comparing PULL and PUSH policies it can be noticed that making the most of the information about finished products stock level, the PULL policy performs better in supplying the primary market by reducing the average waiting time of backorder sales (Figure 3, Figure 5) and the number of delayed sales (Figure 4, Figure 6). This reduction is really outstanding because of high backorder costs and loss of public image risks.

Moreover, the PULL policy supplies the secondary market with a larger amount of products (Figure 4, Figure 6) although the waiting time in the finished products store is significantly higher (Figure 3, Figure 5). However, the increased revenues from secondary market sales cover the increased holding costs. The PULL strategy, therefore, performs better in secondary markets managing.


Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
backorder.queue	0.00	0,00	0.00	0.00	0.00	0.00
FPS.Queue	2.6062	0,06	2.4580	2.7520	0.00	30.0470
manufacturing.queue	2.6055	0,07	2.4922	2.8063	0.00	26.8434
MS.Queue	8.0776	0,32	7.3122	8.5999	0.00014736	68.1472
prod.queue	1.5685	0,02	1.5326	1.6110	1.0000	13.6640
backorder prod.Queue	1.9323	0,01	1.9023	1.9598	0.00000293	16.3733
q1.queue	0.00	0,00	0.00	0.00	0.00	0.00
reman1.queue	0.7946	0,01	0.7705	0.8208	0.00	11.9523
reman2.queue	1.1730	0,02	1.1421	1.2078	0.00	19.2952
reman3.queue	1.8345	0,03	1.7595	1.9003	0.00	49.3463
remanufacturing1.queue	3.9076	0,08	3.7826	4.1510	0.00	27.8013
remanufacturing2.queue	3.2895	0,10	3.0792	3.5494	0.00	25.8052
remanufacturing3.queue	3.1827	0,12	2.9937	3.5406	0.00	23.9796

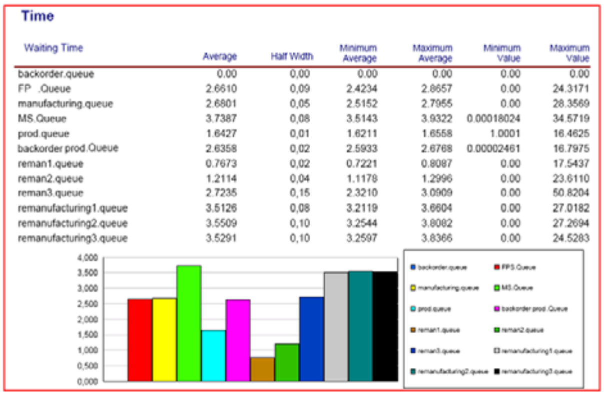
Figure 3: PULL Policy – Waiting Time



Counter

Count	Average	Half Width	Minimum Average	Maximum Average
average	7215.20	51,19	7125.00	7378.00
average for assamble	4336.00	56,61	4213.00	4478.00
bad	4436.80	50,00	4369.00	4543.00
bad for assemble	1334.30	23,87	1279.00	1386.00
dispose average	2879.20	33,95	2799.00	2943.00
dispose bad	3102.50	54,95	3020.00	3264.00
dispose good	760.70	21,24	695.00	800.00
FP	26993.10	65,33	26843.00	27130.00
good	7568.40	91,57	7394.00	7785.00
good for assemble	6807.70	93,62	6629.00	7046.00
lost sales	2960.00	122,40	2649.00	3155.00
man for assemble	14513.90	29,09	14435.00	14561.00
ms1	4421.00	108,37	4181.00	4628.00
overflow average	12.9000	2,95	7.0000	19.0000
overflow bad	327.60	16,61	292.00	362.00
overflow raw	15487.00	29,13	15440.00	15566.00
sales	17467.50	196,23	17064.00	17908.00
sales ms	4420.80	108,98	4178.00	4629.00
backorder sales	9525.50	211,49	9110.00	10017.00
backorder sales ms	0.00	0,00	0.00	0.00
lost sales ms	7588.30	72,74	7444.00	7736.00

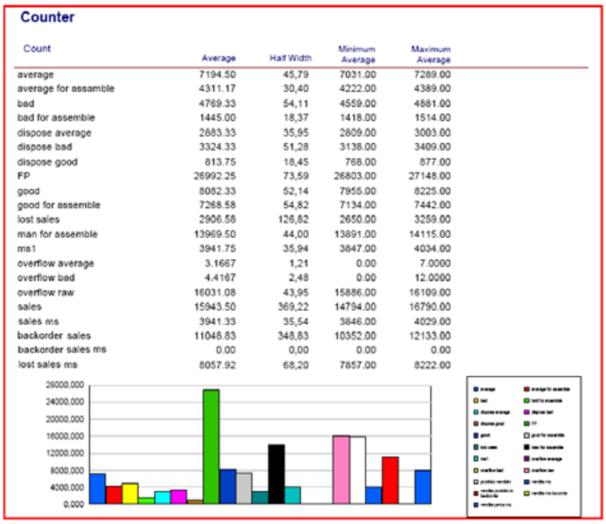
Figure 4: PULL Policy – Products Sold



Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
backorder.queue	0.00	0,00	0.00	0.00	0.00	0.00
FP .Queue	2.6610	0,09	2.4234	2.8657	0.00	24.3171
manufacturing.queue	2.6801	0,05	2.5152	2.7955	0.00	28.3569
MS.Queue	3.7387	0,08	3.5143	3.9322	0.00018024	34.5719
prod.queue	1.6427	0,01	1.6211	1.6558	1.0001	16.4625
backorder prod.Queue	2.6358	0,02	2.5933	2.6768	0.00002461	16.7975
reman1.queue	0.7673	0,02	0.7221	0.8087	0.00	17.5437
reman2.queue	1.2114	0,04	1.1178	1.2996	0.00	23.6110
reman3.queue	2.7235	0,15	2.3210	3.0909	0.00	50.8204
remanufacturing1.queue	3.5126	0,08	3.2119	3.6604	0.00	27.0182
remanufacturing2.queue	3.5509	0,10	3.2544	3.8082	0.00	27.2694
remanufacturing3.queue	3.5291	0,10	3.2597	3.8366	0.00	24.5283

Figure 5: PUSH Policy – Waiting Time

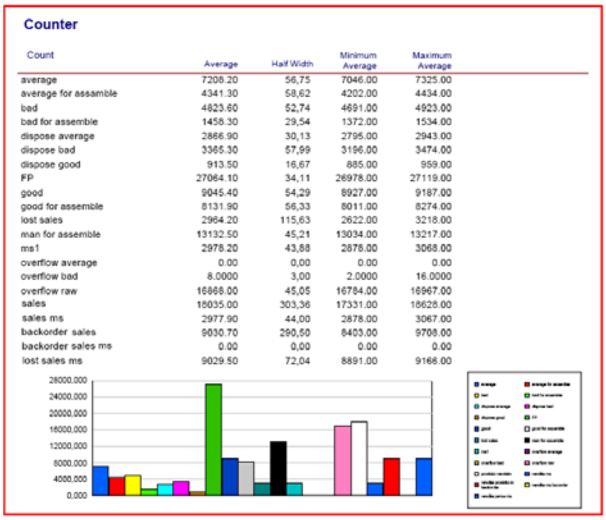


Counter

Count	Average	Half Width	Minimum Average	Maximum Average
average	7194.50	45,79	7031.00	7289.00
average for assamble	4311.17	30,40	4222.00	4389.00
bad	4769.33	54,11	4559.00	4881.00
bad for assemble	1445.00	18,37	1418.00	1514.00
dispose average	2883.33	35,95	2809.00	3003.00
dispose bad	3324.33	51,28	3138.00	3409.00
dispose good	813.75	18,45	768.00	877.00
FP	26992.25	73,59	26803.00	27148.00
good	8082.33	52,14	7955.00	8225.00
good for assemble	7268.58	54,82	7134.00	7442.00
lost sales	2906.58	126,82	2650.00	3259.00
man for assemble	13969.50	44,00	13891.00	14115.00
ms1	3941.75	35,94	3847.00	4034.00
overflow average	3.1667	1,21	0.00	7.0000
overflow bad	4.4167	2,48	0.00	12.0000
overflow raw	16031.08	43,95	15886.00	16109.00
sales	15943.50	369,22	14794.00	16790.00
sales ms	3941.33	35,54	3846.00	4029.00
backorder sales	11048.83	348,83	10352.00	12133.00
backorder sales ms	0.00	0,00	0.00	0.00
lost sales ms	8057.92	68,20	7857.00	8222.00

Figure 6: PUSH Policy – Products Sold

PUSH 2 and *PULL* policies have a quite similar performance with regard to the primary market, while *PUSH 2* policy has poor performance in secondary market management, as the number of sales (and hence the revenue) is significantly lower than in other control policies (Figure 7). This result shows the difficulties *of PUSH 2* policy in managing secondary market.



Counter

Count	Average	Half Width	Minimum Average	Maximum Average
average	7208.20	56,75	7046.00	7325.00
average for assamble	4341.30	58,62	4202.00	4434.00
bad	4823.60	52,74	4691.00	4923.00
bad for assemble	1458.30	29,54	1372.00	1534.00
dispose average	2866.90	30,13	2795.00	2943.00
dispose bad	3365.30	57,99	3196.00	3474.00
dispose good	913.50	16,67	885.00	959.00
FP	27064.10	34,11	26978.00	27119.00
good	9045.40	54,29	8927.00	9187.00
good for assemble	8131.90	56,33	8011.00	8274.00
lost sales	2964.20	115,63	2622.00	3218.00
man for assemble	13132.50	45,21	13034.00	13217.00
ms1	2978.20	43,88	2878.00	3068.00
overflow average	0.00	0,00	0.00	0.00
overflow bad	8.0000	3,00	2.0000	16.0000
overflow raw	16868.00	45,05	16784.00	16967.00
sales	18035.00	303,36	17331.00	18628.00
sales ms	2977.90	44,00	2878.00	3067.00
backorder sales	9030.70	290,50	8403.00	9708.00
backorder sales ms	0.00	0,00	0.00	0.00
lost sales ms	9029.50	72,04	8891.00	9166.00

Figure 7: PUSH 2 Policy – Products Sold

The highest profit is achieved by the *PULL* policy while the *PUSH 2* policy gets the lowest cost (Figure 9). The *PUSH* strategy while getting higher revenues than the *PUSH* one, achieves the lowest profit because of the highest cost.

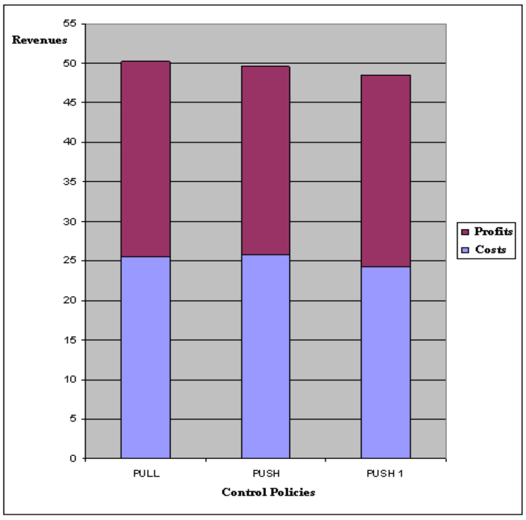


Figure 8: Control Policies – Profit/Cost Analysis

Costs incurred implementing respectively the *PULL*, the *PUSH* and the *PUSH* 2 policy are detailed in Figure 9, Figure 10 and Figure 11 and compared in Figure 12.

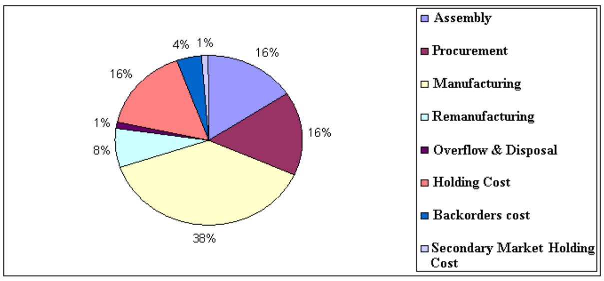


Figure 9: PULL Policy - Costs Detail

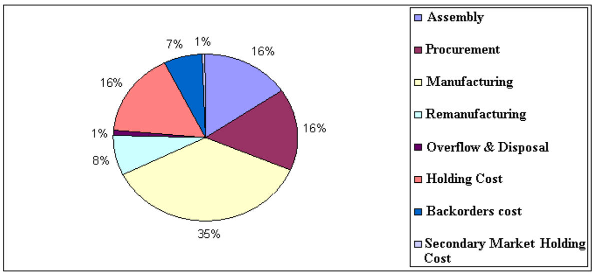


Figure 10: PUSH Policy - Costs Detail

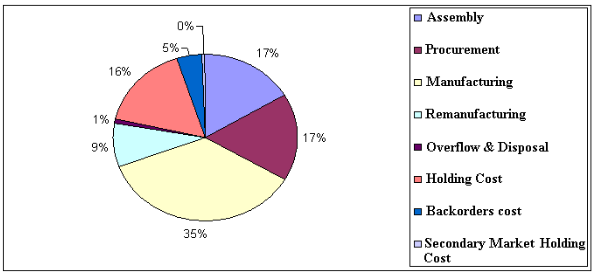


Figure 11: PUSH 2 Policy - Costs Detail

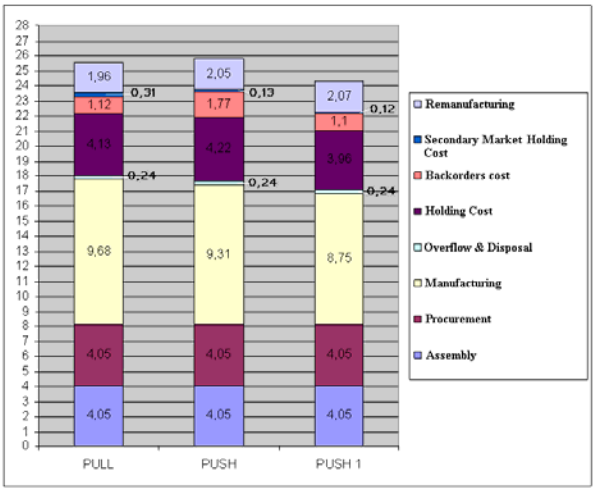


Figure 12: Incurred Costs Comparison

It can be noticed that adopting the *PUSH 2* policy the secondary market is fed with smaller quantities of high quality cores and so less products are manufactured (manufacturing costs are lower) and holding cost are lower (high returns holding cost is lower than manufactured products holding cost). Moreover, remanufacturing costs are slightly higher than those incurred with other control strategies because high quality returns have low remanufacturing costs. So the *PUSH 2* policy has the lowest operating costs. The *PUSH* and *PULL* strategies have a quite similar cost structure, the main difference concerns the high backorder costs incurred with the *PUSH* strategy.

4. CONCLUSIONS

In this paper, three returns management policies for secondary market supplying in Hybrid Manufacturing/Remanufacturing Systems are proposed, which are based upon different stock level control.

Particularly, *PUSH 2* control policy performance is affected by the specific priority rule adopted in the remanufacturing process and so, to effectively compare different policies performance, an analysis is made to carefully choose the rule which allows the *PUSH 2* control policy to work as efficiently as possible.

Summarizing, the *PULL* policy analyzes the inventory level of the warehouse intended for supplying the primary market and decides on a case by case basis how to use high quality returns. In this way the *PULL* policy allows for an improved system processes visibility: finished products stock level has an impact on workstations and upstream buffers state.

The *PUSH* policy is "myopic": it doesn’t care about system buffer state but high quality cores are *a priori* used for the primary or secondary market.

The *PUSH 2* policy is a *middle way* solution, it has a "partial" insight of the system, high quality cores are used according to only the stock level of a certain buffer. So, as information quality increases, system performance increases too.

Note that even if the *PULL* policy economic advantages are noticeable, its implementation is more difficult from an organizational point of view because stocks cannot be independently controlled. So, according to the specific case, some decisions must be taken considering the trade-off between economic benefits and organizational difficulties.

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AUTHORS BIOGRAPHY

M. Gallo is a PhD of “Production Systems and Technologies” (Department of Materials Engineering and Operations Management of the University of Naples “Federico II”). He also has a master degree in mechanical engineering from the University of Naples “Federico II”. At the moment he is a postdoctoral researcher at the aforesaid department. His research interests are several and related to the design and management of production systems for goods and services. In particular he has treated issues concerning quality, maintenance, production planning, environmental sustainability and soft computing techniques applied to industrial fields.

L. Guerra is currently PhD student at the Department of Materials Engineering and Operations Management of the University of Naples “Federico II”. He received his degree in mechanical engineering from the University of Naples “Federico II” (2002). His main research activities are in manufacturing systems organization, management, reconfiguration and dynamic control, artificial intelligence techniques applied to industrial fields, industrial plants safety and security.

G. Guizzi is researcher at the Department of Materials Engineering and Operations Management of the University of Naples “Federico II”. He is a PhD in Aerospace, Naval and Quality Engineering (2006) and he received his degree in management engineering from the University of Naples “Federico II” (2002). His main research activities are in operations management, project management, risk management, simulation techniques applied to industrial fields.