

REFURBURSHING AND RECYCLING FACILITIES DESIGN METHODOLOGY

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Abstract

To design a facility, expected flows between the resources is one of the most important input. Flows are usually calculated given some statistics of previous periods or from the expected demand and the process required. However, in a refurbishing and recycling facility, flows are very fluctuating and not trivial to predict. The quantity produced by such facility not only depends on the demand but also on the supplies which are returned products under guaranty or discarded products after their end-of-use. The uncertainty and the variability on these supplies are often higher than the one on the demand which makes it even more complex to calculate the expected flows. This article contributes a methodology for designing such recycling and refurbishing facilities that are concurrently efficient and robust. It provides an empirical illustration of the methodology through a computer refurbishing and recycling facility case study.

1 Reverse Logistics and Facility Design

Reverse logistics is growing in importance, notably to limit the increase of products reaching landfills and thus reduce their negative environmental and social impact.

Currently, most products are not designed for profitable recycling and refurbishing and thus, there are few facilities that are focused on these types of processes. However, with the help of ecodesign tools and processes, it is to be expected that they will increase in number and size. Ecodesign notably aims to design parts so as to make it easier to salvage products or materials after the end of use or end of life of the products. For example, it promotes designing products for repair or for disassembly. On one side, it is thus becoming more economical to disassemble products yet on the other side the recycling and refurbishing market is still barely profitable, notably due to a general lack of efficiency. In this context, designing, implementing and operating high performance recycling and refurbishing facilities, or zones within wider scope facilities, is a crucial factor for companies to be able to perform and even survive in such an environment. Such facilities have to address stochastic process flow complexity and offer-demand matching dynamics [1]. This chapter contributes a methodology for designing such recycling and refurbishing facilities with the aim of concurrent high efficiency, flexibility and robustness. It uses a computer hardware refurbishing and recycling facility case [1,2] as context for illustrating the methodology and its outcomes.

The chapter is structured as follows. Section two addresses the key complexity issues in recycling and refurbishing facilities. Section three introduces our proposed design methodology. Section four provides the illustrative case study and its results. Finally section five provides concluding remarks and avenues for further research.

2 Refurbishing and Recycling Facility Layout Complexity

Reverse logistics presents numerous characteristics making facilities design and planning quite challenging [1,2]. Indeed, even if the logistics network might simply look like the “reverse” of a forward logistics system, the roles of its players are less obvious and operations are more complex due to multifaceted uncertainty. For example, the daily quantity and arrival time of discarded products are usually unknown and hard to predict with precision, as well as their overall inbound rate. The wide variety of products increases this uncertainty.

If there is uncertainty in the input process, there is even more in the decision process. Among the routinely made decisions, one must evaluate each product unit to decide whether or not it will be repaired. If so, then one must determine which parts will be needed for repairing it. If not repaired, then one has to decide whether the product parts can and should be reused in other products. Further decisions deal with whether these parts should rather be disassembled aiming to recycle raw material as much as possible while discarding in a landfill what cannot be recovered. The operational process is thus characterized by numerous sorting and evaluation steps. In this proposed methodology, we consider that products from different types and models, between which parts are interchangeable, are part of a same product group.

To provide substance to the methodological and model development, Figure 1 adapted from [2] provides a generic process mapping for computer recycling and

refurbishing. There are decisional nodes and physical nodes representing key activities such as cleaning, repairing, disassembly for parts and disassembly for raw material. Although it has been proposed for computer recycling and refurbishing, it is generic enough to be applicable for any goods which have parts and can be repaired except for step G, software installation and computer configuration, which can be replaced by reconfiguration of the product if applicable.

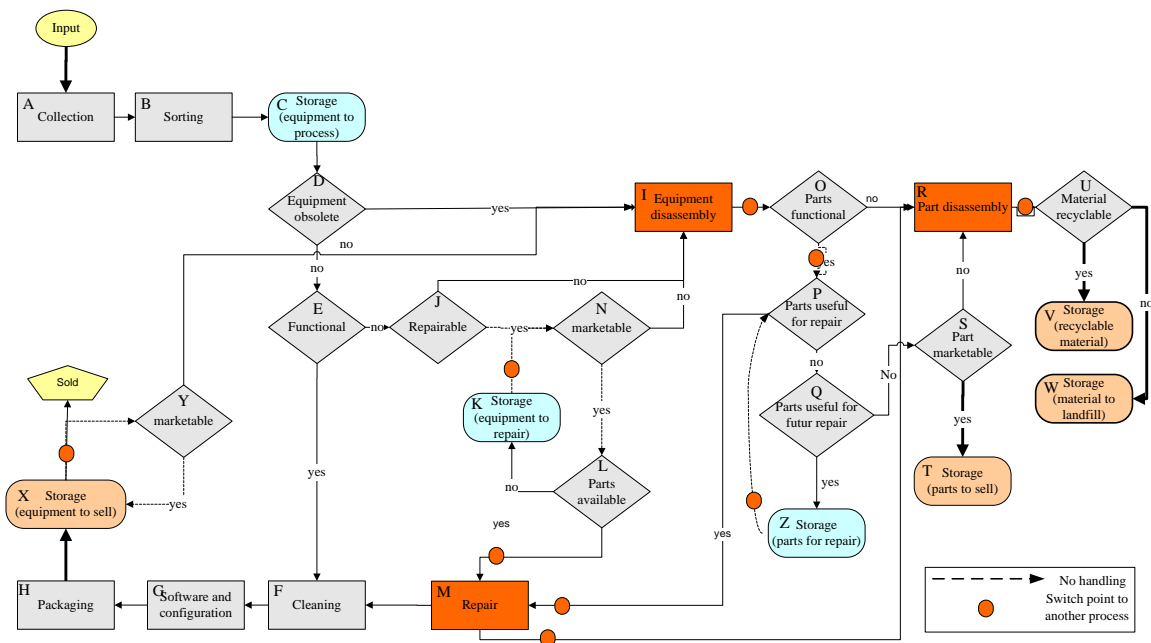


Figure 1. Mapping of the generic refurbishing and recycling process

The refurbishing and recycling process can also be described as a tree (starting with the incoming product) with a huge number of roots (whose extremities correspond to objects (products, parts and materials) in various states, each having specific branching (with object state probabilities and decisions).

Since some products such as computers have a short lifecycle, they have a high obsolescence rate. So at each sorting step of the process, even if the part evaluated is in good condition, one needs to validate the value of the part. Should it be kept? Will it potentially be reused, or are there already too many of its type in inventory? If so, decision must be taken as to whether or not it will be disassembled to gather components and materials or be discarded to landfill. The value of short lifecycle salvaged products and parts is thus fast evolving and hard to assess. This fluctuating value impacts the probability of sorting decisions at every step of the recycling process, thus making flow and inventory management more complex. The physical flows between production resource types are thus highly stochastic.

Demand and offer matching issues have significant impact on the flow patterns in a recycling and refurbishing facility. Set in the personal computer market, the demand and offer for refurbished computers of a given product group both exhibit a time lag of several months relative to the sales of new computers of this same group. This time lag is related to the type of consumers and the length of time the consumer is using the product before getting rid of it. This is often associated to either the increasing malfunctioning of the product or the arrival on the market of newer models that functionally outclass the current generation of products. When the latter occurs, the demand for the original new products declines. The percentage of the new product sales that is returned as the refurbished offer varies according to the country depending on the presence or not of a law reinforcing the “clean” discarding of products such as high-value electronics and computers. Overall, the refurbished offer for a given product group is quite irregular. This structural and stochastic gap between demand and offer makes inventory levels even harder to predict and to manage.

When units of a given product group are brought in for refurbishing, they may be gradually transformed into a series of derivatives that can coexist in a facility: ready-to-be-sold refurbished products, to-be-repaired products, ready-to-use parts, ready-to-be-sold parts, to-be-recycled raw materials and to-be-discarded raw materials. Furthermore, in a refurbishing and recycling facility, different groups of products, often in distinct lifecycle stages, must often share the resources available. This makes the flows even harder to manage and to predict.

The next section will describe the proposed facility design methodology and how it integrates issues related to the offer-demand matching.

3 Facility Design Methodology

As depicted in the previous sections, the flows are very complex and the whole environment is characterized with a lot of uncertainty, leading to a need for efficient and robust facilities. The facility design methodology presented in this section aims to enable engineers to design such facilities. It builds on the modeling introduced by Marcotte et al. [7] and the HoloDesign holographic facilities design methodology and platform from Marcotte and Montreuil [5]. Sub-problems of the model introduced by Marcotte et al. [7] are integrated in various steps of the proposed four-phase design methodology. These phases are briefly described here and an example of an implementation through a case study is presented in Section 4.

The first phase performs dynamic processing plan estimation. It generates a processing plan estimate assuming that the goal is to maximize profit for the planning horizon covered by the lifecycle of the product. It specifies, for each period of a product lifecycle, the number of products (computers) to refurbish or to discard as well as for parts to be reused, sell or recycled given the forecasted offer and demand for each period. This phase requires three steps. The first step translates the mapping of Figure 1 into a list of linear processes, where a process describes the operations required for a product to

changed status (e.g. to-be-repaired products transformed into a ready-to-be-sold). The second step uses the forecast of the sales of new products introduced into the market to forecast the offer of end-of-use products and demand for refurbished products, parts and recycled materials along the lifecycle. The third step generates a processing plan estimate assuming that the goal is to optimize profit for the periods covered by the lifecycle of a specific product group while using the information from the last two steps. The goal is also to salvage as soon as possible the maximum value of products, parts and material to avoid having them stored longer than necessary.

It is important to note here that each product group is most likely at a different stage of its lifecycle at a given point in time. However, when optimizing profit, we can presume that the demand pattern for a given product group can be forecast a priori, by predicting when new product groups will be introduced on the market, and knowing the demand for other product groups. Thus the processes and the profit can be optimized for each product group individually. Steps 2 and 3 of this first phase must thus be repeated for each product group.

The second phase is about dynamic processing resources planning. It combines, for each period of the planning horizon, the production to be done for each product group given their lifecycle stage. It then computes the aggregate capacity requirements for each type of production resource (workstations) over each period in the planning horizon.

The third phase corresponds to stochastic production scenarios generation that will be used to optimize the layout in phase 4. To model the stochastic nature of the quantity to produce, each probabilistically generated scenario specifies on a daily basis, the set of products to be received on the inbound side and the demand for each product and part on the outbound side. This phase applies an optimization model similar to that of phase 1 in order to determine the short term production planning, for example each day of a month, for each product group. It thus specifies the quantity of products or parts that are expected to be processed under each manufacturing process for each sub-periods of a given period of the studied horizon. However, the probability distributions of the offer and the demand in phase 1 are dynamic along the lifecycle of a product group as opposed to more stable ones for phase 3 since it is covering a shorter length of time. Indeed, phase 1 optimizes the number of products following each process, but on the long term since the goal is to estimate the dynamic processing plan. In the planning horizon covered in phase 1, the average “demand” is varying through the lifecycle of a product group which is not the case in phase 3. The model of phase 1 is applied again but this time by assuming that the average daily quantity to be produced for each “product” is equal to the monthly quantity divided by the number of operating days. These values are generated assuming that the values used as input in phase 1 are the average values for a period (month). This will provide the information that will be used by the layout optimization tool to estimate the flow.

The fourth and last phase focuses on the design of efficient and robust layouts and on the estimation of the induced flow patterns, provided the scenarios generated in the third phase. The methodology used is adapted from the methodology proposed in [5] and is illustrated in Figure 2. It aims to generate a given number of robust layouts that can later

be submitted to other criteria. This phase is at a daily production level as opposed to a monthly level in phase 1. In this phase, it is important to consider all the products from all the product groups at once because they will compete for workstation capacity. The steps required for this phase are briefly described here. However, the reader can find more details in [5].

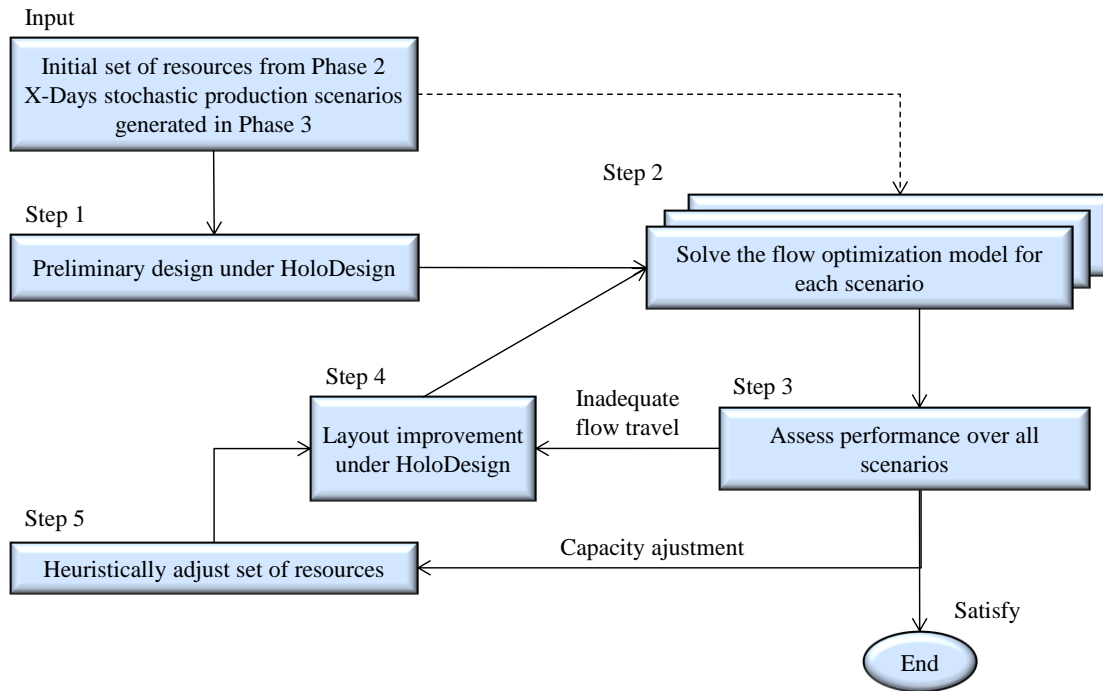


Figure 2. Phase 4: Layout optimization and robustness evaluation

The main inputs of phase 4 are the set of resources that has been computed in phase 2 and the stochastic production scenarios generated from phase 3, as opposed to the original methodology in [5]. Indeed, as described in section 2, the computer refurbishing and disassembly process is characterized by many aspects. These aspects are quantified and are used to generate sets of scenarios which will be used to evaluate the layout robustness. An initial layout is then generated in step 1. This layout is evaluated under each scenario in step 2 and the robustness is then computed in step 3. If there is adequate capacity but inadequate flow travel, the layout is improved under HoloDesign in step 4 and the new layout is then evaluated, back to step 2. If there is not enough capacity, the set of resources is heuristically adjusted in step 5. Other adjustments can be made in step 5, such as selecting equipment type for a given operation such to improve the fluidity of the flows or modifying the set of resources to study the impact on the facility's overall performance of production planning strategy such as levelling. Finally, step 1 is repeated until a sufficient number of robust layouts have been generated.

4 Example of an Implementation Through a Case Study

This section shows an implementation of the methodology through a case study and results obtained from each phase are presented and discussed. To study the design of refurbishing and recycling facilities, we have chosen to focus on the case study of a computer refurbishing and recycling facility. The case which we refer to is taken from [2] to which we add values and parameters for a typical case. It focuses on computers and all the derivatives that can result from refurbishing and recycling. As shown in Figure 1, it includes all possible processes from simply cleaning a computer and repacking it with new components like a mouse and a keyboard, to disassembling computers or storing parts that can be used to repair other computers later. It even includes disassembling parts if no better salvage value can be taken from them. Some limits have been set, for example on the storage capacity or to reflect the fact that after a certain period of time, a sale is lost if the backorder state is too long. This section focuses on discussion and insights about understanding the methodology and what it aims to be able to process as information and to obtain as output rather than on the numerical results.

4.1 Example of Phase 1: Dynamic Processing Plan Estimation

The first step of the first phase lists the processes that are followed by derivatives of a typical product. Appendix 1 lists the processes and describes them briefly. As we can see in this list, a computer received in the facility (A) can be either processed to be ready for sale (X) (process P1), or identified as a computer which is not functional (M) (process P5) and needs repair. If the computer is ready for sale and there is a demand at that period, it can then follow process P12 and be sold, or it can be stored (P10) and will be available to sell in a future period. If it is stored, it can still be disassembled later (P11) if no sales opportunities are forecasted in a near future. Using Figure 1, it is easy to see the multiple combinations and sequences of processes that a computer and its parts can follow.

In this implementation, and as reflected in Appendix 1, we have chosen to group all the material coming from the disassembly of parts into two very basic categories: recyclable material and material to be sent to landfill. Also, we assume three types of parts to model the problem. The first type represents parts which are usually the first to break and the third represents the parts that rarely break, the second being somewhere between these two extremes. This is important to keep in mind when studying the impact of the probability of a part to be defective and the variation in the inventory level. It is to be noted that any number of types of parts could be modeled using this methodology.

The quantities to be processed of each derivative product of a given product group at each period of its lifecycle, shown in Figure 3, are estimated according to a demand-offer forecast. The graph has been truncated, to better show the values of most of the products, as products 34 and 35, corresponding to the recyclable material and material to be sent to the landfill respectively, have very high values compared to the number of computers processed. As one can see, the quantities to produce are very irregular and depend on the

stage of the lifecycle. It contrasts periods where all the computers on hand are refurbished and sold (e.g. high sales from 15 to 21), periods where sales are lost because the offer is much lower than the demand and there is not enough inventory on hand to cover the demand (e.g. lost sales from 13 to 18), periods where the offer is so much higher than demand that almost all of the computers coming to the facility are disassembled (e.g. disassembling parts from 31 to 40). As to be expected, since part type 1 is usually the one to break first, it is also the one which is the least available for repair. If there are some extra parts of type 1, they will rarely go to recycling since others facilities which are refurbishing the same product group will probably need those parts. On the other hand, the parts that have a high probability of functioning correctly are the most available but the less required either for the repair process or by consumers of parts. For such parts, the best salvage value is achieved by recycling raw material instead of keeping too many units in inventory for a long period of time before finally recycling them. So it is most likely that parts from these three types of parts will follow different flow patterns in the facility.

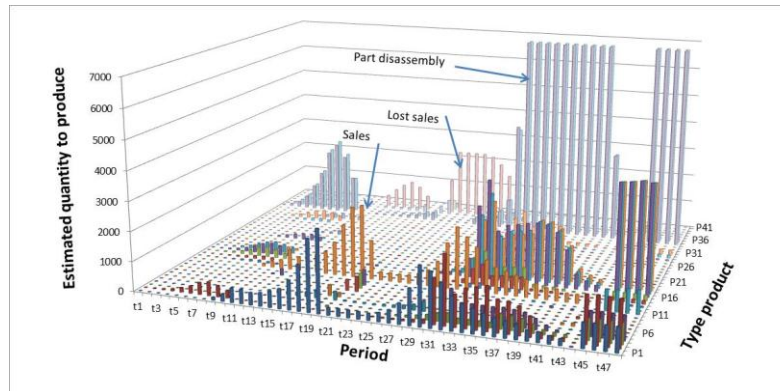


Figure 3. Estimated quantity to produce of each derivative products of a given product group at each period of the lifecycle

4.2 Example of Phase 2: Dynamic Processing Resources Planning

The estimated quantities obtained in the first phase are used to estimate the capacity requirements for each type of workstation for each product group. Figure 4 shows the estimated number of workstations of each type and for each period for one product group over its lifecycle. The figure shows the high variations in capacity requirements.

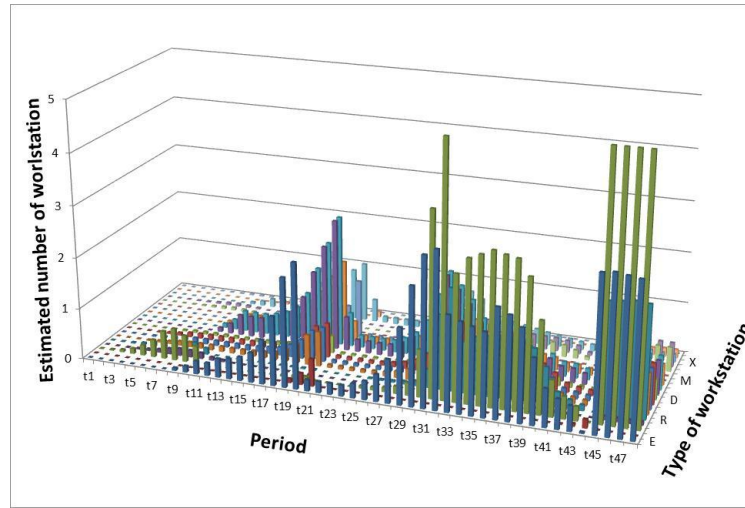


Figure 4. Estimated number of workstations of each type and for each period for one product group over its lifecycle

Since many product groups are processed at the same time in a facility, the combined capacity requirements must be estimated by adding the estimated capacity requirements for each product group according to which period they are in their respective lifecycle. These combined capacity requirements are shown in Figure 5. We see here that the variations are less pronounced for a given type.

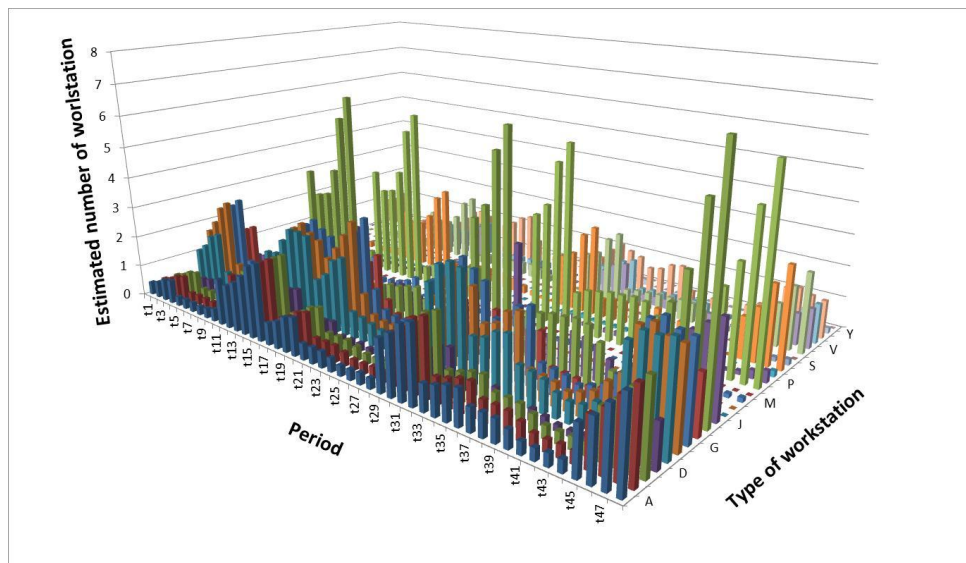


Figure 5. Number of workstations of each type required at each period

One must note that in the implementation, to avoid dramatic variations, we have applied partial levelling by limiting the production or the storage of some products. Even thus, there are still important variations. One modification that could be done is to create storage for computers to be disassembled for the parts and storage for the parts that are to be disassembled for the raw material. This would imply more material handling, but be less extreme in the workstation capacity requirements. Further study would be needed on the trade-offs. These variations occur because the lengths of time between peeks are probably too long to fully level the production for example of disassembling parts. This might be related to the data used and could lead to different results if the lifecycles are shorter.

4.3 Example Phase 3: Stochastic Production Scenarios Generation

The third phase of the methodology generates the stochastic production scenarios. It applies a similar optimization model to the one used for phase 1. Since the planning horizon is shorter, we have considered that the costs, the revenues and the offer and demand probability distributions are stable over the planning horizon. However, any probability distribution could have been used through the planning horizon.

In this implementation, we have assumed that the planning horizon is of one month decomposed into 20 working days as a typical average. The stochastic values for the daily demand and offer for a given product group are generated assuming that the average value is the offer and demand for that month used in phase 1. These have been generated for three product groups assuming Group A is a very popular and very active product group in the facility, Group B is declining in popularity and Group C is only starting to be thrown away by first users. Figure 6 shows the quantity to produce for each product of each product group and for each day of the month.

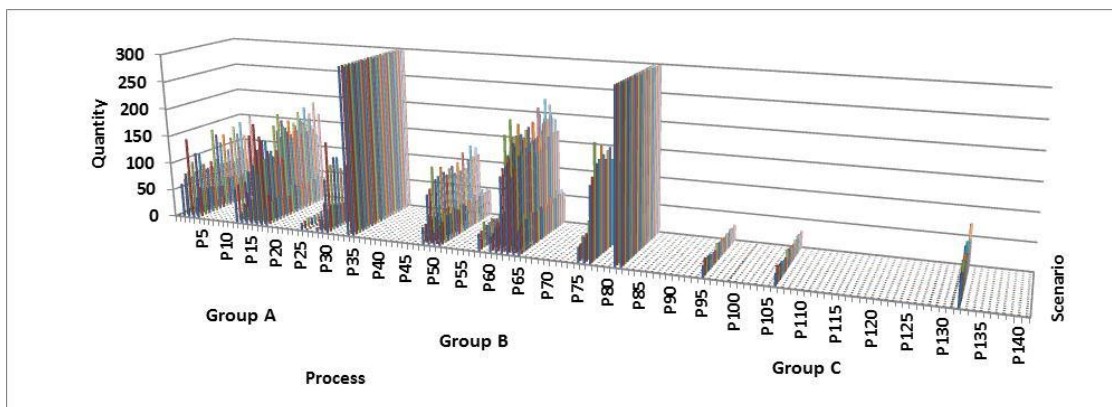


Figure 6. Quantity to produce for each product of each product group and for each day of the month

4.4 Example Phase 4: Layout Optimization and Robustness Evaluation

The last phase uses the estimated capacity requirements from phase 2 and the stochastic production scenarios generated in phase 3. The layouts can be optimized for each month or for a length of time equivalent to the lifecycle of a product group. Figure 7 shows a layout with a number of workstations sufficient for any period of the planning horizon which is equivalent to a product lifecycle. This implies that the usage of some workstations may depend on the requirements for that period. The picture on the left shows an example of the flow patterns in a high production period and where only few workstations are not required. On the contrary, the one on the right shows an example of the flow patterns in a low production period where many workstations are not used. In Figure 8, the middle left part of the facility is enlarged to show the flows of products that are disassembled for parts and then for recycling. The flow intensity increases as it goes through disassembly. In this figure, the thickness of the line is proportional to the intensity of the flows; one can notice that the most intense flows are between workstations which are close by. The layout generated thus enables the creation of efficient routings.

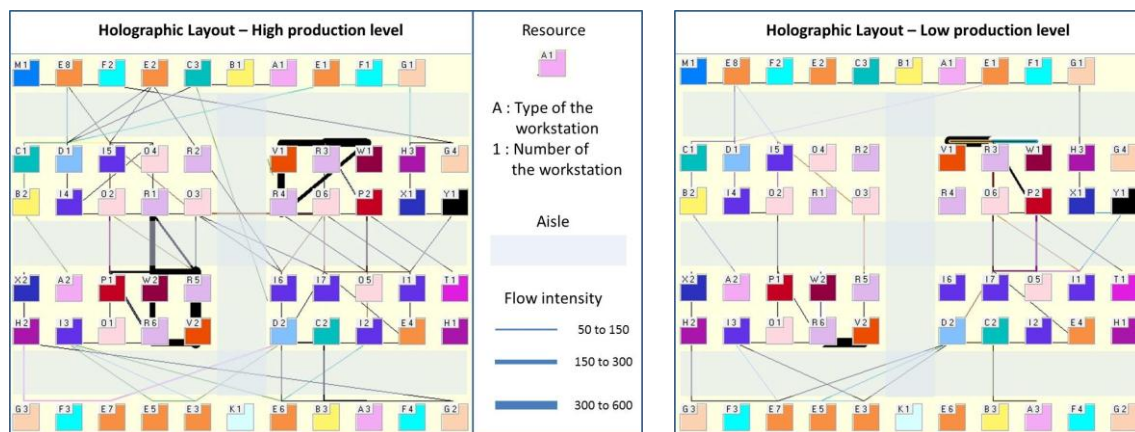


Figure 7. Examples of flow patterns in a high and in a low production period

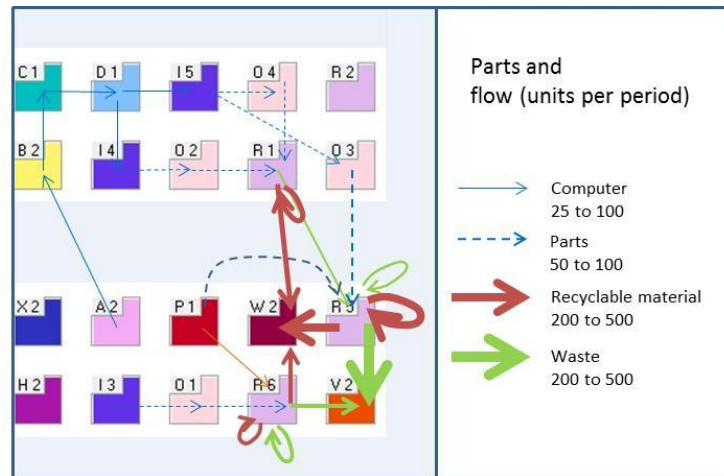


Figure 8. Zooming on flow patterns in a high production period

The layouts generated are evaluated during the design procedure under a set of 60 scenarios which is composed of three subsets of 20 scenarios each. These subsets each represent one month of production which is a set of 20 scenarios or days of production for which the demand has been randomly generated according the probability distribution of the offer of used computers and the demand for refurbished computers and parts. These three sets respectively represent low, medium and high total flow intensity. The evaluation of the layouts is embedded in the design procedure such that if a generated layout performs poorly compared to the best previous ones obtained, it is discarded before evaluating it with all of the scenarios. The score of a layout for a given scenario is equal to the sum of all the flows times the distance between the resources. To enable the comparison of the scores for different flow intensity periods, the score is normalized by dividing the score of a layout for a scenario by the total number of material handling moves required between the resources for that scenario. For example, if the demand for a given product is 10, and it has a process with 5 operations, it will imply 4 material handling moves times 10 units. Thus the normalized score is equal to the average distance travelled per move.

To better grasp the performance of holographic layouts, facilities have been designed using the proposed methodology and compared to randomly generated layouts which have the same number of each type of resource than the proposed methodology specifies. Randomly generated layouts have been taken for comparison since holographic layouts look like random layouts at first glance. The 10 best randomly generated layouts have been selected from a set of 16,000 randomly generated layouts. The 10 best holographic layouts have been generated using the proposed methodology.

Figure 9 shows the normalized score of the 10 best holographic layouts compared to the 10 best randomly generated layouts under three different levels of flow intensity. Some layouts have a score below 1 in some processes; indeed two consecutive operations can be performed on the same resource if the capacity and capabilities of the resource

allows it and thus the material handling is not required. Each line of the graph is the set of normalized scores for a given layout over the 3 sets of 20 scenarios. It is clear that the performance of the holographic layouts generated using the proposed methodology compare favourably to the randomly generated ones. The figure also depicts the robustness of the holographic layouts. Since it shows less variability along a given month, it is more stable.

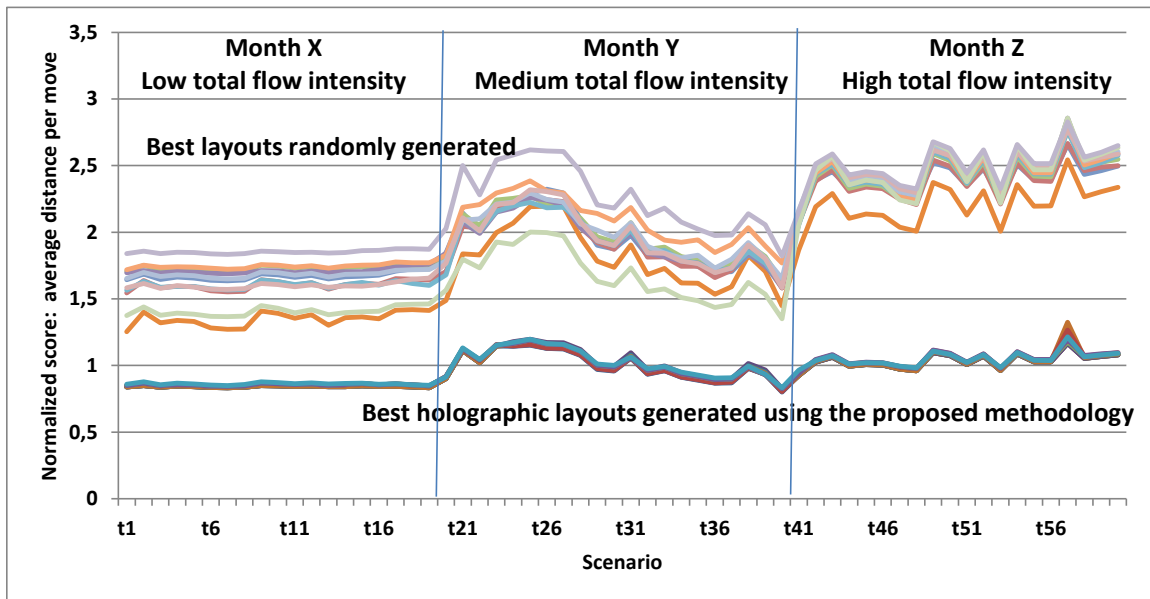


Figure 9. Contrasting the expected performance of best random and holographic layouts

This section has shown the implementation of the methodology with a case study. Even if some results will differ from one case to another, such as the number of workstations required, there are some insights that can be generalized. For example, computers and parts will follow different flow patterns according to their obsolescence, their probability of being functional and repairable and their marketability.

5 Conclusions

Refurbishing and recycling facilities design offers a lot of challenges to researchers. To design a robust and efficient facility, one must not only refer to the demand and the offer patterns. The lifecycle of each product calls for different planning strategies at its various stages, which impacts dynamically on the flow patterns. This paper proposes an overall design methodology and provides an implementation example through a computer refurbishing and recycling facility case study.

The main contribution of this paper is the proposed refurbishing and recycling facility design methodology. It takes into consideration the lifecycle pattern of a product group,

which also means that it combines, for a given period, the demand and offer for each group according to the stage in which they are in their respective lifecycles.

It also integrates the assembly and disassembly processes by decomposing the generic process into processes specific to products in a given state and to parts. It ensures flow balance at the workstations such that the parts resulting from a product disassembly leave the workstation that received and disassembled the computer. It also ensures flow balance for workstations that use disassembled parts to repair computers and for raw material coming from parts being disassembled.

Even if it has been illustratively applied to a computer refurbishing and recycling facility, the method is generic enough to be applied to any refurbishing and recycling facility, whether all or only part of the generic process of Figure 1 is involved.

The methodology takes advantage of HoloDesign, a holographic facilities design methodology and platform integrating layout and flow optimization given a set of workstations, information about products and processes if available and evaluating the robustness of a facility through a Monte Carlo simulation.

The research focused on robust facility design. The goal has been to design a stable layout delivering high performance over its life cycle. This eliminates the need for dynamic relayouts and their significant efforts and costs. However, there are cases when relayout costs and efforts are inherently low, for example when manually refurbishing small-size products. In such cases, an adaptable design could be preferable to a robust design. Such an adaptable design would dynamically enable altering the layout easily based on current and foreseeable demand and operating conditions, such as seasonal peaks and valleys whenever pertinent. Means include designing the facility so that sections of the facility can be closed and opened according to the production pace, as well as designing the facility so as to exploit the capabilities of easy-to-move equipment. Adaptable facilities design is a promising research avenue.

The proposed methodology can be extended to the design of the network of facilities on a given territory. Indeed, each facility is equivalent to a workstation with given capabilities and capacity. The products flow from a production resource to another, where in this case, the resources are located in different buildings, cities or countries. Networks are actually local as well as global. Some computers actually travel to other continents where countries with low-priced labor are recycling them. It is not only an economical matter of who will process the products and of the network of facilities, but also about regulations and the impact on the environment and on the population.

Acknowledgements

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References

- [1] Marcotte, S., Hallé, M.-E. and Montreuil, B. “Computer Hardware Reverse Logistics: A Field Study of Canadian Facilities”, K.E., R.M. M.K.O., B.A.P., G.D.T., J.U., (ed.), *Proceedings of the Progress in Material Handling Research*: 2008, 370-389 (2008).
- [2] Hallé, M.-E. *La logistique inverse d'un ordinateur : une étude terrain des entreprises québécoises*, Master thesis, Université du Québec à Montréal, 140 p. (2009).
- [3] Montreuil, B. and Venkatadri, U. “Scattered Layout of Intelligent Job Shops Operating in a Volatile Environment”. In: *Proceedings of International Conference on Computer Integrated Manufacturing*, ICCIM, Singapore (1991).
- [4] Olivier C., B. Montreuil & P. Lefrançois, “Design of Operational Planning and Control Systems for Factories Organized as Flexible Networks of Processors”, *Proceedings of 2nd World Automation Congress*, Montpellier, France, (1996).
- [5] Marcotte, S. *Conception d'usines holographiques*, Ph. D. thesis, Faculté des sciences de l'administration, Université Laval, Québec, 410 p. (2005).
- [6] Marcotte, S., Montreuil, B. (2003) “Factory Layout Robustness Evaluation under Stochastic Demand”. *IERC Conference proceedings*, IIE, Mai 2003, Portland, Oregon, U.S.A. (2003).
- [7] Marcotte, S. Montreuil, B. and Durand, M. “Robust Design of Computer Refurbishing and Recycling Facilities”, *INFORMS Conference*, Nov. 2010, Austin, USA, (2010).
- [8] Montreuil, B. “A Modelling Framework for Integrating Layout Design and Flow Network Design”, *Progress in Material Handling and Logistics*, v2, ed. by J.A. White and I.W. Pence, Springer-Verlag, 95-116 (1991).

Appendix 1 List of Processes

Number	Description		Process
P1	Computer processed and ready to be sold	A-X1	A-B-C-D-E-F-G-H-X
P2	Computer obsolete or without market	A-I	A-B-C-D-I
P3	Computer out of order to be disassembled	A-I'	A-B-C-D-E-J-I
P4	Computer repairable but not marketable	A-I''	A-B-C-D-E-J-Ne-I
P5	Computer to repair	A-M	A-B-C-D-E-J-Ne-Le-M
P6	Computer to repair, parts missing	A-K	A-B-C-D-E-J-Ne-Le-K
P7	Computer stored to be repaired, no market	K-I	K _{i-1} -Nk-I
P8	Computer to be repaired, stored again	K-K	K _{i-1} -Nk-Lk-K
P9	Computer send to repair	K-M	K _{i-1} -Nk-Lk-M
P10	Computer ready to be sold, kept in storage	X-X	X _{i-1} -Y-X
P11	Computer ready to be sold, no market	X-I	X _{i-1} -Y-I
P12	Computer sold		Sale
P13	Part type 1 tested and is functional	I1-P1	I1-O-P1
P14	Part type 2 tested and is functional	I2-P2	I2-O-P2
P15	Part type 3 tested and is functional	I3-P3	I3-O-P3
P16	Part type 1 tested, not functional, to disass.	I1-R1	I1-O-R1
P17	Part type 2 tested, not functional, to disass.	I2-R2	I2-O-R2
P18	Part type 3 tested, not functional, to disass.	I3-R3	I3-O-R3
P19	Parts type 1 send to repair	P1-M	P1-M
P20	Parts type 2 send to repair	P2-M	P2-M
P21	Parts type 3 send to repair	P3-M	P3-M
P22	Parts type 1 send to storage	P1-Z1	P1-Q-Z1
P23	Parts type 2 send to storage	P2-Z2	P2-Q-Z2
P24	Parts type 3 send to storage	P3-Z3	P3-Q-Z3
P25	Parts type 1 sold	P1-T1	P1-Q-S-T1
P26	Parts type 2 sold	P2-T2	P2-Q-S-T2
P27	Parts type 3 sold	P3-T3	P3-Q-S-T3
P28	Parts type 1 , no market, to disassembly	P1-R1	P1-Q-S-R1
P29	Parts type 2 , no market, to disassembly	P2-R2	P2-Q-S-R2
P30	Parts type 3 , no market, to disassembly	P3-R3	P3-Q-S-R3
P31	Parts type 1 stored need check for market again	Z1-P1	Z1-P1
P32	Parts type 2 stored need check for market again	Z2-P2	Z2-P2
P33	Parts type 3 stored need check for market again	Z3-P3	Z3-P3
P34	Parts disassembled for raw material recyclable	R-V	R-U-V
P35	Parts disassembled for raw material landfill	R-W	R-U-W
P36	Back-order from last period	X-X	X _{i+1} -X (Back Order)
P37	Computer repaired and ready to be sold	M-X	M-F-G-H-X
P38	Sale losts		Lost sales
P39	Buy new parts type 1	AA1-M	AA1-M
P40	Buy new parts type 2	AA2-M	AA2-M
P41	Buy new parts type 3	AA3-M	AA3-M