Economic Analysis of End-of-Life Computer Systems in Educational Institutions

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ABSTRACT

In this paper we address the operational and economical aspects of EOL computer systems at educational institutions. To this end we present an actual case study of a major university in Boston and provide an economical analysis of different options such as disposal, disassembly, recycling, reuse and re-sale of these systems. We recommend a new procedure that will improve the collection and handling processes leading to a structured decision making methodology.

Key Words: Disassembly, Recycling, Reuse, Electronics, Universities, Operations Research, and Optimization

1. INTRODUCTION

The growth in the world's population and the rapid enhancements in technology have started to seriously strain the environment.[3, 7] As a response to the increasing deterioration of the environment, countries around the world have started to respond to this growing problem. Several countries in Europe have enacted regulations, which encourage manufacturers to account for the life cycle of their products. For example, manufacturers in Germany are required to take back and process certain products at the end of their lives. Newly introduced laws in the United States have also started to put pressure on consumers to dispose of some of the end-of-life (EOL) products in a responsible manner. For example, Massachusetts has recently banned the disposal of computer monitors and TVs into landfills.

As the working lives of computer systems become shorter, the number of computer systems disposed, reused or recycled will become even larger. One of the largest users of computer systems are educational institutions. Until recently the educational institutions were able to dispose of their computer systems like any other non-hazardous products. However, in light of the recently enacted laws, some components or portions of the computer systems are now considered hazardous and as such require special handling and/or processing, making the EOL disposal problem much more complex. Recently, this problem was further exaggerated due to the push to make all computers Y2K compliant. This resulted in the retirement of even more computer systems, many of which are still waiting in the storage ready to be recycled, reused or remanufactured. However, products need to be separated into their constituent components via disassembly before they can be recycled, reused or sometimes even disposed of. Disassembly has proven its role in material and product recovery by allowing selective separation of desired parts and materials.[1, 4, 5] However, disassembly, though crucial, is an expensive process. Therefore, performing disassembly in a cost effective manner is important.

In this paper we address the operational and economical aspects of EOL computer systems at educational institutions. To this end we present an actual case study of a major university in Boston and provide an economical analysis of different options such as disposal, disassembly, recycling, reuse and re-sale of these systems. We recommend a new procedure that will improve the collection and handling processes leading to a structured decision making methodology.

2. NEEDS ANALYSIS

In Massachusetts, 75,000 tons of electronic products are discarded annually. 25,000 tons of these are monitors from computers and TVs.[2] Educational institutions are among the largest contributors to this phenomenon. In regular recycling facilities (state managed or private) there is a great uncertainty in the number and the condition of the returned products. This uncertainty makes the implementation of a structured recycling and disassembly process costly. However, in well-established educational institutions where there is a high demand for computers, monitors, etc., the uncertainties are greatly minimized.

Returned product rate is highly unpredictable for regular recycling facilities since there is no control over who disposes what, when and where. On the other hand, for educational institutions the returned product rate is more controlled since there is a set budget for what and when to buy and policies regarding the time to discard old computers and electronic products. Most importantly when they buy these products they tend to buy them from one manufacturer in large quantities with long-term agreements. This also helps in predicting the condition of returned products. All the laboratories, faculty and administrative computers are under the control of the inventory policies and are generally returned in batches according to set terms (3 to 5 years) and are replaced with new batches of brand new computers. Table 1 summarizes the various recycling characteristics of the regular recycling facilities and educational institutions.

3. GOALS

The goals of this study are as follows:

- To analyze and evaluate the collection, disassembly or disposal of Y2K non-compliant computers at Northeastern University (NU).
- To determine an optimum solution for handling used computers at NU.

Table 1. Comparison of Regular Recycling Facilities and Educational Institutions

Criteria	Regular Recycling Facilities	Educational Institutions
Returned product rate	Unpredictable	Predictable
Returned product condition	Unpredictable	Predictable
Life Cycle Period	Unpredictable	Predictable
Variety of returned products	High	Low
Recycling Facilities	Exists	Non-existent
Transportation	Unpredictable	Predictable
Collection effort costs	High	Low
Recycling Processes	Exists	Non-existent

4. LABORATORY RESEARCH AND ANALYSIS

In order to achieve the above-mentioned goals we worked with the staff of NU's Information Systems Customer Services (ISCS) Department. During the time when this study was conducted, the ISCS staff was in the process of removing the Y2K non-compliant computers from various departments of the university. Our study started with the experimental disassembly of some of the retrieved computers to identify the components (and their conditions) that would be practical to retrieve from the various brands of computers (Table 2). NU collected approximately one thousand computers from various departments, ninety percent of which were IBM Value Point 486, five percent were NEC 386 and 486, three percent were HP 386, and the rest were very old machines of mixed brands (Figure 1). Some of the computers were donated to public schools and churches while a few others were sent to Trinidad (Table 3). The bulk of the computers (94% of all the returned Y2K non-compliant computers) were sent to recycling facilities for disposal.

The Project Manager of the Y2K retrieval of non-compliant computers undertaking at the time did not have sufficient manpower to remove the network cards and to erase the hard drives let alone disassemble the computers and retrieve the valuable components for profit or re-use. All the computers that were sent to schools, churches or Trinidad were sent with the understanding that the recipients will check the computers and dispose of the dysfunctional ones themselves. During our research we discovered that the university did not have the most up to date inventory data on their computers. The information received from the University Asset Department still had computers in their records that were disposed of more than a couple of years ago. Even the computers that were replaced during the Y2K project were still in the database. There were computers for which the university had IP addresses but the computers were non-existent or the Asset Department did not know of their physical locations. A new system, which the university is in the process of installing, will not only help in computer recovery, but also help in maintaining the computers and provide customer support.

5. EXISTING METHODS

ISCS collects old PCs from all departments, faculties and computer laboratories. First, ISCS removes the network card and erases the hard drive; after that ISCS tries to find a means of disposing these computers. Some of the CPUs and monitors were donated to schools, churches or foreign countries. The remaining computers were sent to garbage collection companies. Out of the 1000 Y2K non-complaint computers that were dispersed, a total of 60 CPUs found homes and 940 were disposed of at $8 a piece.

Table 2. Disassembly Study

BRAND	Arche	IBM	IBM	IBM	IBM	IBM	NPC	Gateway	Gateway	Link	Zenith	Ambra	Ocs	Havpavge
Model	Arche	466 Dx2/Dp	466 DX2/D	P60D	330	425 SX/S	NPC	4Dx-33v	4Dx2-66v	link 486	Z-386Sx	Ambra	Ocs	486
Case/Chassis	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Motherboard	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CPU	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hard Drive	x	x	x	x	x	x	x		x	x	x	x	x	x
Ram	x	x	x		x	x	x		x	x	x	x	x	x
Floppy 3 1/2	x	x	x	x	x	x	x	x	x	x	x			x
Floppy 5 1/4	x		x			x	x			x	x	x	x	x
Power Supply	x	x	x		x	x		x	x	x	x	x	x	x
CD Rom Drive		x		x	x			x	x					
Network Card	x	x	x	x	x						x			
Modem Card													x	x
Video Card	x	x			x		x		x	x	x	x		x
Controller Cards	x						x	x		x		x	x	x
SCSI Card		x		x									x	
Tape Backup														

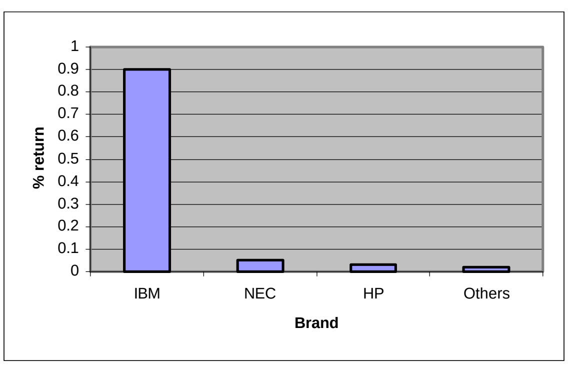

Figure 1. Returns

Table 3. Donations

Trinidad, West Indies	12 NEC 486's
	3 Dell 486's
Cambridge Signal Tech	2 Havpavge 486's
	3 Home Made 486's
Sciutate Public Schools	24 NEC 486's
	1 IBM 484
	1 HP 386
Newton Presbyterian Church	14 NEC 486's

6. PROBLEM FORMULATION

6.1 Notation

The following notation are used throughout the paper:

BE	Environmental benefit per lb. of non-disposal
Cr_i	Cleaning and refurbishing cost/component *i*
Cr_m	Cleaning and refurbishing cost/monitor
Cs	Sorting & dismantling cost/computer
CWc	Disposal cost per lb.-computer
CWm	Disposal cost per lb.-monitor
d	% of computers that can be sold (demanded)
Dc	Disposal cost per computer
Dm	Disposal cost per monitor
DC	Number of disposed computers
DM	Number of disposed monitors
N_c	Number of total computers on hand
Nc_i	Number of each component *i* for each computer
N_i	Number of different types of components per computer
N_m	Number of total monitors on hand
NC_p	Number of partially disassembled computers
r	% disposed partial computers
Rc_i	Revenue for each component *i* sold
RC	Revenue for each computer sold
RM	Revenue for each monitor sold
RW	Revenue/lb.-computer recycled
Sn_i	Number of sold component of type *i* for *i*=1…*n*
SC	Number of sold computers
SM	Number of sold monitors
TC	Total Cost
TP	Total Profit
TR	Total revenue
W_i	Weight of component *i*
W_m	Total weight of each monitor
W_T	Total weight for each computer

6.2 Formulation

We present a mathematical programming formulation to maximize the total profit from collection and processing of EOL computers in educational institutions (refer to the previous section for the explanation of notation).

6.2.1 The Objective Function

The objective function consists of maximizing the total profit, which is the difference between the total revenue and the total cost and can be written as follows:

$$\text{Maximize } Z = TP = TR - TC \tag{1}$$

The expressions for total revenue and total cost can be derived as follows.

Total Revenue

Total revenue is the sum of revenues from computer sales, monitor sales, component sales, recycling and environment benefit, where

$$\text{revenue from computer sales} = SC * RC \tag{2}$$

$$\text{revenue from monitor sales} = = SM * RM \tag{3}$$

$$\text{revenue from component sales} = \sum_{i=1}^{n} Sn_i * Rc_i \tag{4}$$

$$\text{revenue from recycling} = [(N_c - SC - DC - NC_p) * W_T - (1-r)[NC_p * W_T - \sum_{i=1}^{n} (Sn_i * W_i)]] * RW \tag{5}$$

Note that in equation (5), $(N_c - SC - DC - NC_p)$ represents the number of computers recycled without disassembly and $[NC_p * W_T - \sum_{i=1}^{n} (Sn_i * W_i)]$ represents the weight of partially disassembled computers.

revenue from environmental benefit =

$$[SC*W_T + SM*Wm + \sum_{i=1}^{n}(Sn_i*W_i) + [(N_c - SC - DC - NC_p)*W_T - (1-r)[NC_p*W_T - \sum_{i=1}^{n}(Sn_i*W_i)]]]*BE \quad (6)$$

Therefore, from (2) - (6)

$$TR = SC*RC + SM*RM + \sum_{i=1}^{n} Sn_i*Rc_i + [(N_c - SC - DC - NC_p)*W_T - (1-r)[NC_p*W_T - \sum_{i=1}^{n}(Sn_i*W_i)]]*RW + [SC*W_T + SM*Wm + \sum_{i=1}^{n}(Sn_i*W_i) + [(N_c - SC - DC - NC_p)*W_T - (1-r)[NC_p*W_T - \sum_{i=1}^{n}(Sn_i*W_i)]]]*BE \quad (7)$$

Total Cost

Total cost is the sum of costs from disposal of computers, disposal of monitor, sorting & dismantling, and cleaning & refurbishing, where

$$\text{disposal cost of computers} = DC*Dc + r*[NC_p*W_T - \sum_{i=1}^{n} Sn_i*W_i]*CW_c \quad (8)$$

$$\text{disposal cost of monitors} = DM*Dm \quad (9)$$

$$\text{sorting \& dismantling cost} = Nc*Cs \quad (10)$$

$$\text{cleaning \& refurbishing cost} = \sum_{i=1}^{n} Cr_i*Sn_i + SM*Cr_m \quad (11)$$

Therefore, from (8) - (11)

$$TC = DC*Dc + r*[NC_p*W_T - \sum_{i=1}^{n} Sn_i*W_i]*CW_c + DM*Dm + Nc*Cs + \sum_{i=1}^{n} Cr_i*Sn_i + SM*Cr_m \quad (12)$$

6.2.2 The Constraints

The following constraints apply in the formulation

$$(1/d)*SC \le Nc \quad (13)$$

$$DC \le Nc \quad (14)$$

$$SM + DM = Nm \quad (15)$$

$$\sum_{i=1}^{n} Sn_i*Rc_i \le \sum_{i=1}^{n} N_i*Nc_i*Rc_i \quad (16)$$

$$[(N_c - SC - DC - NC_p)*W_T - (1-r)[NC_p*W_T - \sum_{i=1}^{n}(Sn_i*W_i)]] \le Nc*W_T \quad (17)$$

$$[SC*W_T + SM*Wm + \sum_{i=1}^{n}(Sn_i*W_i) + [(N_c - SC - DC - NC_p)*W_T - (1-r)[NC_p*W_T - \sum_{i=1}^{n}(Sn_i*W_i)]]] \le (Nc*W_T + Nm*W_m) \quad (18)$$

$$DC * Dc + r*[NC_p*W_T - \sum_{i=1}^{n} Sn_i*W_i]*CW_c \leq Nc*W_T*CW_c \quad (19)$$

$$DM \leq Nm \quad (20)$$

$$(1/d)*SM \leq Nm \quad (21)$$

$$\sum_{i=1}^{n} Cr_i*Sn_i \leq \sum_{i=1}^{n} Cr_i*N_i*Nc_i \quad (22)$$

$$r \leq 1.00 \quad (23)$$

Non-negativity Constraints

$$SC \geq 0,\ SM \geq 0,\ DC \geq 0,\ DM \geq 0,\ NC_p \geq 0,\ Sn_i \geq 0\ \forall\ i = 1....(Nc_i*N_i) \quad (24)$$

6.3 Assumptions:

Because of the state regulations, there is no value generated by recycling the computers. They are either sold or disposed of. Because the computers retrieved under the Y2K project were manufactured in the early 1990s, the components are worthless in today's market, i.e., $Rc_i = 0,\ \forall\ i = 1,...,n$.

We assume that each computer will go through sorting and testing before a decision is made to sell, disassemble or dispose it of. On the other hand, cleaning and refurbishing costs are incurred for individually sold components and monitors

6.4 Experimentation Data:

The experimental data is based on actual figures obtained from ISCS during the Y2K retrieval project and "The San Jose Computer Collection and Recycling Pilot" project.[6] The hourly rate for cleaning and refurbishing of monitors has been assumed to be $10 which is the typical rate paid to students to do this kind of work. The individual weights were estimated based on the San Jose Pilot project's figures for total weight and total number of computers or monitors collected.[6] Environmental Benefit cost has been estimated using the "DEP's 1998 CRT/Electronics Recycling Strategy COST/BENEFIT ANALYSIS".[2] The experimental data used in the model is given in Table 4.

6.5 Model Simplification:

Because of the assumptions made in 6.3, we can further simplify the model. The simplified formulation is as follows:

Maximize Z =

$$SC*RC + SM*RM + [(N_c - SC - DC)*W_T*RW] + [SC*W_T + SM*Wm + (N_c - SC - DC)*W_T]*BE$$
$$- DC*Dc + DM*Dm + Nc*Cs + SM*Cr_m$$

Subject To:

$$(1/d)*SC \leq Nc$$

$$DC \leq Nc$$

$$SM + DM = Nm$$

$$[SC*W_T + SM*Wm + [(N_c - SC - DC)*W_T]] \leq (Nc*W_T + Nm*W_m)$$

$$DC * Dc \quad Nc \quad W_T \quad CW_c$$

$$DM \le Nm$$

$$(1/d) * SM \le Nm$$

Non-negativity Constraints

$$SC \ge 0,\ SM \ge 0,\ DC \ge 0,\ DM \ge 0,$$

Table 4. Experimentation Data

BE	\$ 0.23	N_i	14
Cr_i	various	N_m	1000
Cr_m	\$ 5.00	RC	\$ 33.69
Cs	\$ 7.72	Rc_i	\$ 0.00
CWc	\$ 0.18	RM	\$ 12.63
CWm	\$ 0.5	RW	\$ 1.33
Dc	\$ 8.00	W_i	various
Dm	\$ 17.97	W_m	35.94 lb.
N_c	1000	W_T	25.32 lb.
Nc_i	1		

7. EXPERIMENTS AND RESULTS

The assumption of not to disassemble the computers simplified the model dramatically. We experimented with the model using 10 different demand rates. Demand rate, *d*, was varied from 0.1 to 1.0 in increments of 0.1. The optimum total profit for each experiment is shown in Figure 2. In every experiment, the model found that the CPUs were able to satisfy the demand and the remaining ones were recycled. For monitors, however, the model suggested to sell the monitors to satisfy the demand and then disposing the remaining ones (Table 5).

8. CONCLUSIONS

The mathematical model suggests that disposal is the least recommended solution for NU under the assumed scenarios. The biggest challenge is to find a demand for these old computers. The NU's ISCS Department chose to dispose of a high percentage of computers due to labor, space and time constraints, even though there was a demand and some value for the computers and monitors. NU's ISCS Department was neither ready nor prepared to deal with such a large unexpected and unplanned retrieval project. They were forced by the University to be the designated department to handle this issue. For generating revenue, a mature infrastructure is necessary. There is a need for a system that would maintain retrieval and re-use process for the University. To do this, the University needs to have a better control over the inventory of their electronic equipment and an established forecast model for the return of equipment. Finally, there needs to be a department with the facility and labor necessary to make this a profitable venture for the university and friendly to the environment.

9. FUTURE RESEARCH

- Analyze and evaluate the periodic collection, disassembly and disposal of computers at Northeastern University (NU).
- Design an infrastructure for the retrieval and reuse of electronic equipment at NU.
- Expand this study to other educational institutions in Massachusetts and study the impact and economic feasibility.
- Ease the constraints and assumptions in this model and apply them for different frequency of collection rates and time intervals.

Table 5. Total Profit for Different Demand Rates

Demand	SC	DC	Recycle Computers	SM	DM	Total Profit
0	0	0	1000	0	1000	453
0.1	100	0	900	100	900	5676.62
0.2	200	0	800	200	800	10900.24
0.3	300	0	700	300	700	16123.86
0.4	400	0	600	400	600	21347.48
0.5	500	0	500	500	500	26571.1
0.6	600	0	400	600	400	31794.72
0.7	700	0	300	700	300	37018.34
0.8	800	0	200	800	200	42241.96
0.9	900	0	100	900	100	47465.58
1	1000	0	0	1000	0	52689.2

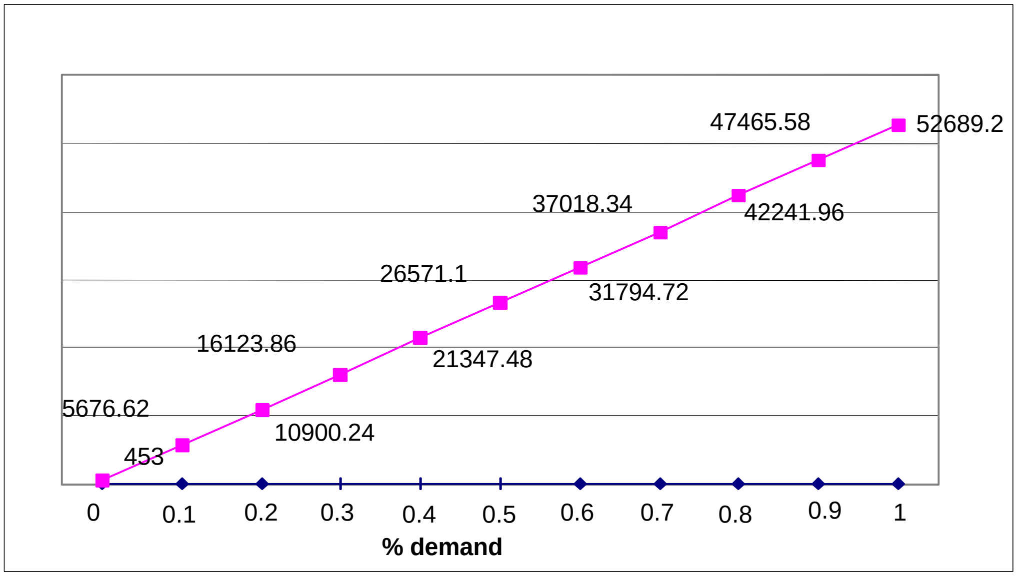

Figure 2. Experimentation Results

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