E-waste Dismantling: Profitable at the cost of Occupational Hazard?

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***Abstract*— The Objectives of this study are to (i) determine the profit obtained and the occupational hazard faced by dismantlers per day in the two major e-waste recycling sectors (formal and informal) in developing countries like India, China, and Africa, (ii) compare the profits obtained in these two sectors by taking the dismantling processes of two computer electronics systems: CRT monitor and CPU as a case study, in order to identify which sector obtains greater profit, (iii) identify the ratios of profit/occupational hazard ('P' index) and dismantler salary/occupational hazard ('S' index), in order to identify which sector carries out more efficient dismantling, (i.e., employ dismantling techniques that provide a better tradeoff between the profit obtained and the occupational hazard faced) and (iv) understand how the retrieval process of more number of parts within an organised dismantling process which uses appropriate dismantling techniques influences both the profit obtained and the occupational hazard faced in the formal sector compared to those in the informal sector where fewer parts are retrieved using crude dismantling techniques.**

***Index Terms*— Profit, Occupational hazard, e-waste dismantling, dismantler salary, recycling sectors**

I. INTRODUCTION

As per the CPCB Guidelines [1], 'E-waste' is defined as "waste generated from used electronic devices and household appliances which are not fit for their originally intended use and are destined for recovery, recycling and disposal". In developing countries like India, China and Africa, e-waste dismantling and recycling is carried out by two major recycling sectors: formal and informal. "The formal sectors are not well-networked but have contacts with large IT companies and organizations, from which they buy e-waste through tenders and auctions" [2]. However, "the informal sector has better reach in collection due to the ubiquitous spread of scrap collectors and is also able to offer better prices for the e-waste. They can afford to do so as they do not pay taxes and employ low cost labour in crude working conditions within minimal investments in equipment", as reported by a study conducted by ELCINA [3]. In both these e-waste recycling sectors, activities such as collecting, sorting, dismantling, reuse and recycling are very common. In particular, manual dismantling is an integral part of recycling in developing countries [2].

"In India, if working conditions of dismantlers are analyzed closely, it can be seen that the health of dismantlers are not only affected by them being exposed to harmful substances, but also by the poor ergonomic working conditions they encounter while dismantling" [4]. In our earlier study [2], two potential factors: effort and ergonomic hazard, represented respectively using Disassembly Effort Index (DEI) per day & ergonomic hazard per day, were identified as contributing to occupational hazard (physical and not exposure hazards) associated with e-waste dismantling processes, which were assessed in the study using these two factors. The hypothesis "Formal/organized recycling sectors have relatively less occupational hazard than do Informal/unorganized recycling sectors" was also verified with data from dismantling processes for three computer electronics products in real recycling scenarios in developing countries. It was found that the formal sector had less occupational hazard than did the informal sector, as evidenced by the fact that both average DEI per day and average ergonomic hazard per day for the same set of products were higher in informal sectors than in formal sectors. Also, a crucial observation made in that study was that, the number of products dismantled per day per person was much higher in informal sectors than in formal sectors, while the level of dismantling per product (i.e. the average number of dismantling steps in a product) was less in informal sectors. Is this trend due to the influence of 'economic factor' on e-waste dismantling?

In this study, therefore, e-waste dismantling processes have been investigated from both economical and health hazard perspectives in order to obtain a better understanding of the e-waste dismantling scenarios in developing countries.

II. METHODOLOGY

Two products have been chosen for carrying out this study: CRT monitor and CPU, for the following reasons: (i) Since consumption of these products is high in both developed and developing countries and since each of these contains a significant amount of precious metals, these products are the most frequently dismantled during their End of Life (EoL) phases. Thus, studying the dismantling

978-1-4799-1802-7/15/$31.00 ©2015 IEEE

processes of these products will help understand the real occupational hazard faced by dismantlers; (ii) dismantling processes of these products have significant implications on both environment and economy [2].

Data Collection: Data collection includes the following data: (i) recyclable parts retrieved after dismantling, (ii) recyclable material of parts [5] [6], (iii) part weight (Kg), (iv) resale value for dismantled parts (INR /Kg) and labour cost per unit, and (v) number of CRT monitors or CPUs dismantled per day [2] were collected from two e-waste traders located in Pondicherry and Madurai, India, In this way, Data were collected for both the sectors for two computer electronics: CRT monitor and CPU [see Tables 1 & 2].

Table 1. Data collection for formal sector

Products dismantled	Formal sector			
	Parts retrieved after dismantling	Recyclable material	Part wt. (Kg)	Resale value (INR/Kg)
CRT monitor	Main Cables	Copper (No 2 insulated)	0. 15	50
	Connection wires	Copper (No 2 insulated)	0.3	50
	Plastic casing	Plastic	3	18
	CRT	Lead oxide Glass, steel	9.8	Dumped
	PCB (low grade)	Mixed, Gold, Al	0.85	100 per no
	Deflector yoke	Copper (No 2 insulated)	0.15	130
CPU	Power supply	Aluminum, Copper	2.2	50
	Ribbon cables	Aluminum, Copper	0.3	Dumped
	Connection wires	Copper (No 2 insulated)	0.5	50
	Hard drive	Mixed	0.9	65 per no
	Metal casing	Steel	4	18
	PCB (green board)	Mixed, Gold, Al	0.45	280
	Other small boards	Mixed	0.3	40
	CD drive unit	Mixed	0.9	100 per no

Table 2. Data collection for informal sector

Products dismantled	Informal sector			
	Parts retrieved after dismantling	Recyclable material	Part wt. (Kg)	Resale value (INR/Kg)
CRT monitor	Mixed wires	Copper (low grade)	0.45	50
	Plastic casing	Plastic	3	18
	CRT	Lead oxide Glass, steel	9.8	Dumped
	PCB (low grade)	Mixed, Gold, Al	0.85	100 per no
	Deflector yoke	Copper (No 2 insulated)	0.15	130
CPU	Mixed wires	Copper (low grade)	0.45	82
	Metal casing	Steel	4	18
	PCB (green board)	Mixed, Gold, Al	0.45	280
	Other components	Mixed	-	Dumped

Data Analysis:

(i) Resale value (R.V.) per unit was calculated as follows:

Example:

Weight of Main cables in one CRT monitor = 0.15 kg

Resale value of 1kg of Main cables = 50 INR

Thus, Resale value of 0.15 kg (R.V. per part) = 7.5 INR

In this way, resale value was calculated for each part of both CRT monitor and CPU. Then, resale values for all parts of CRT monitor were aggregated to obtain the resale value for one CRT monitor (R.V per unit). Similarly, resale value for one CPU was calculated. Based on the level of dismantling, number of parts retrieved will vary between the formal and the informal sector. Thus, resale value per unit will also vary [see Table 5].

(ii) Labour cost (L.C.) incurred per dismantler per day was calculated as follows:

Example:

Labour cost (L.C.) incurred per dismantler per day is the same as salary obtained per dismantler per day.

Labour cost per CRT monitor dismantled in the formal sector (L.C. per unit) = 30 INR

Number of CRT monitors dismantled by one dismantler per day in the formal sector = 20 units

Thus, L.C. per dismantler per day in the formal sector for CRT Monitors = 6oo INR

Similarly, Labour cost incurred per dismantler per day was calculated for each sector, for dismantling each product [see Table 5].

(iii) Profit made per dismantler per day was calculated as follows:

Example:

Resale value obtained by selling all dismantled parts of a CRT monitor (R.V. per unit) = 196 INR

Cost price (C.P.) of a CRT monitor per unit =100 INR

R.V. per unit – C.P. per unit = 96 INR

Profit per unit = (R.V. – C.P.) – L.C. 96 – 30 = 66 INR

Profit per dismantler per day in formal sectors for CRT monitors = Profit per CRT unit * Number of CRT monitors dismantled by one dismantler per day in the formal sector =

66 * 20 = 1320 INR

In this way, Profit made per dismantler per day was calculated, for each sector, for dismantling each product [see Table 5].

Figure 1. Pile of CRT monitors waiting to be dismantled in the formal sector at Cape town, South Africa [9]

(iv) Occupational Hazard faced by a dismantler per day was calculated as follows:

The dismantling processes in both the sectors (formal and informal) were studied for two potential factors (DEI & ergonomic hazard) that contribute to the occupational hazard faced while dismantling e-waste. These two factors were analyzed and assessed in our earlier study [2]. As mentioned in [2], the effort taken to dismantle a single unit was evaluated by a Disassembly Effort Index (DEI) model [7], and the ergonomic hazard associated with dismantling more than one product unit was evaluated using MSD Risk Assessment Checklists [8]. The reasons behind choosing these two methods for determining the occupational hazard faced during the dismantling processes of the above mentioned computer electronics are discussed in our earlier work [2]. The approaches followed in these two methods for assessing the DEI and ergonomic hazard are also described in detail in the earlier work [2].

For the dismantling process of CPU in the formal sector, DEI and ergonomic hazard were re-calculated using the DEI model and hazard checklists respectively as shown in Table 3. This is because, the complete dismantling process is considered in the current study in order to reflect the correct financial aspect of the dismantling scenario. For the other dismantling processes, results of both DEI and ergonomic hazard [see Table 4] for the dismantling processes of CRT monitor in formal and informal sectors and CPU in the informal sector were taken from our earlier study [2] for use in the calculation of Occupational hazard [see Table 5] and 'P' and 'S' indices [see Tables 6 & 7].

Figure 2. (i) A dismantler dismantling a CPU (left) (ii) Stock of CPU casings retrieved after dismantling in the formal sector in Bangalore, India [4]

The Occupational hazard faced by a dismantler per day was quantified by multiplying disassembly effort spent by one dismantler in a day (DEI score per day) and ergonomic risks undergone by the same dismantler for the same day (ergonomic hazard per day) [see Table 5]. The underlying reason behind multiplying these two factors in order to calculate the Occupational hazard is that, it was found in our earlier study that DEI score per day and Ergonomic hazard score per day does not correlate with each other.

Occupational hazard faced per day = DEI score per day * ergonomic hazard per day

Table 3. Calculation of DEI and ergonomic hazard for CPU dismantling in formal sector

DEI score for CPU dismantled in formal sector

Formal unit location: Bangalore, India
Source: Video taken in Techlogic unit

Dismantling steps	Time taken	Tools	Fixture	Access	Instruct	Hazard	Force	DEI
Removal of 4 screws to remove the back cover	96s 15	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	41
Removal of side cover by sliding	6s 1	Hand 2	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (push) 2	23
Removal of 2 screws on bottom cover to remove power supply	40s 9	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	35
Removal of 9 screws to remove PCB and other small boards	196s 24	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	50
Removal of hard disk by unscrewing 2 screws	45s 9	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	35
Removal of CD drive unit by unscrewing 2 screws	45s 9	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	35
Removal of front cover	77s 13	Hand 2	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (leverage) 12	45
Removal of 2 screws to remove plug and wires	34s 7	Screw driver 4	Two hands 6	Nil	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	33

Total disassembly time = 8min 59s
Total DEI score = 297

Ergonomic hazard for CPU dismantled in formal sector

Formal unit location: Bangalore, India
Source: Video taken in Techlogic unit

Dismantling steps	Tools used	Time taken for 20 units	Body movement while doing the task	Ergonomic hazard	
				Caution Zone	Hazard Zone
Removal of all components from CPU	screw drivers (flat, T8 star bits), pliers, hammer	3 hours	Working with the neck or back bent more than 30 degrees (without support and without the ability to vary posture) more than 2 hours total per day.	Awkward posture 2	Nil
		2 hr 32 mins	Gripping screw driver with a grip force greater than 10 pounds (equivalent to 44.5 N) for more than 2 hours total per day	High hand force 6	Nil

Figure 3. Heap of CRT monitor casings retrieved after dismantling in the informal sector at Ghana, West Africa [10]

Figure 4. Heap of computer wires waiting for sorting in the informal sector at Guiyu, China [11]

Table 4. DEI score per day and ergonomic hazard per day for both the sectors

	Formal sector		Informal sector	
	CRT monitor Dismantled at Cape town, South Africa [Fig 1.]	CPU dismantled at Bangalore, India [Fig 2.]	CRT monitor dismantled at Ghana, West Africa [Fig 3.]	CPU dismantled at Guiyu, China [Fig 4.]
DEI score per day	5440	5940	3350	12800
Ergonomic hazard per day	0.1	1	4	5

Table 5. Values for (i) R.V per unit (ii) L.C, Profit made and Occupational hazard faced per dismantler per day in both sectors

	Formal sector		Informal sector	
	CRT monitor	CPU	CRT monitor	CPU
Resale value per unit (R.V.)	196	430	196	235
Labour cost per unit (L.C.)	30	30	2	1
Number of units dismantled by one dismantler per day	20	20	50	100
Labour cost per dismantler per day	600	600	100	100
Cost price per unit (C.P.)	100	200	100	200
R.V. – C.P.	96	230	96	35
Profit made per dismantler per unit (R.V. – C.P.) – L.C.	66	200	94	34
Profit made per dismantler per day	1320	4000	4700	3400
Occupational Hazard faced by one dismantler per day	544	5940	13400	64000

(v) 'P' index and 'S' index were calculated as follows:

'P' index is defined as the ratio of Profit made per dismantler per day to the Occupational hazard faced by a dismantler per day [see Table 6].

$$\text{'P' index} = \frac{\text{Profit made per dismantler per day}}{\text{Occupational hazard faced by a dismantler per day}}$$

'S' index is defined as the ratio of Salary obtained per dismantler per day to the Occupational hazard faced by a dismantler per day [see Table 7].

$$\text{'S' index} = \frac{\text{Salary obtained per dismantler per day}}{\text{Occupational hazard faced by a dismantler per day}}$$

Table 6. Comparison of 'P' index scores between both the sectors

'P' index		
	Formal	Informal
CRT monitor	2.426 >	0.350
CPU	0.673 >	0.053

Table 7. Comparison of 'S' index scores between both the sectors

'S' index		
	Formal	Informal
CRT monitor	1.102 >	0.007
CPU	0.101 >	0.001

From the tables shown above, it can be seen that, both 'P' and 'S' index scores are higher for the formal sector compared to the informal sector for both the products dismantled.

III MAJOR FINDINGS

(i) A formula for quantifying Occupational hazard faced by a dismantler per day has been developed.

(ii) Two types of indices, namely: 'P' index and 'S' index have been defined for determining the trade-off between profit obtained and occupational hazard faced during dismantling processes of e-waste.

(iii) Occupational hazard faced by a dismantler per day has been determined for formal and informal sectors for the dismantling processes of two computer electronics products (CRT monitor and CPU) using the equation in Section II point (iv).

(iv) Both 'P' and 'S' index scores have been calculated for each of the sectors (formal and informal) for the dismantling processes of two computer electronics products (CRT monitor and CPU) using the equation in Section II point (v).

(v) Profit made by a dismantler per day has been determined for each sector (formal and informal) for the dismantling processes of two computer electronics products (CRT monitor and CPU).

(vi) Resale value per unit has been determined for CRT monitor and CPU dismantled in both the sectors (formal and informal).

IV INFERENCES

(i) Comparison of the 'P' index and 'S' index scores for the two sectors shows that while the formal sector meets a higher profit per day in CPU dismantling processes, the informal sector interestingly obtains a higher profit per day in the dismantling processes of CRT monitors. This is despite the fact that the informal sector implements cruder dismantling techniques compared to the dismantling techniques implemented in the formal sector.

(ii) *In CRT monitor dismantling*: The informal sector attained a much higher profit per day with a high marginal difference than the formal sector, but 'P' index and 'S' index scores of the informal sector were lower compared to the corresponding scores for the formal sector. This implies that the occupational hazard faced by dismantlers in the informal sector outweighed the profit attained by this sector.

(iii) *In CPU dismantling*: Formal sector attained a higher profit per day with a lower marginal difference than the informal sector. 'P' index and 'S' index scores of the formal sector are also higher compared to the corresponding scores for the informal sector. This indicates that the occupational hazard faced by dismantlers in the formal sector were relatively less compared to the profit attained by this sector than it did for the informal sector.

(iv) The dismantling techniques implemented in the formal sector have a higher 'P' index and 'S' index scores for both the products (CRT monitor and CPU) dismantled compared to the corresponding scores of the dismantling techniques carried out in the informal sector, for dismantling the same products. This indicates that the dismantling techniques used in the formal sector were more efficient than those carried out in the informal sector for dismantling these types of computer electronics.

(v) The number of parts retrieved from a single unit in a dismantling process carried out in the formal sector was higher than those retrieved in the informal sector, for each type of products dismantled (CRT monitor and CPU) [see Table.1]. Retrieving more number of parts in the formal sector actually contributed to a very high (R.V.-C.P.) per CPU unit dismantled and equal (R.V.-C.P.) per CRT monitor dismantled in the formal sector than the informal sector where fewer number of parts were retrieved during the dismantling processes [see Table.5]. But, other factors such as less dismantler salary and the huge number of units dismantled per day in the informal sector seem to have added significantly to the profit attained by them per day and made their profit more or less equal to, or in some cases, higher than the profit attained by the formal sector. This is in spite of the formal sector retrieving more number of parts using proper dismantling techniques during dismantling processes. But overall the study indicates that the trade-off between profit or salary with hazard tilts in favour of the formal sector.

V ACKNOWLEDGEMENT

The authors would like to acknowledge Mr. Bala Sundar from Enviro metals waste management, Pondicherry and Mr. Chandru from Vijay Traders, Madurai for sharing their data on resale value of e-waste components and dismantler salary.

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