Comparison of disassembly effort and ergonomic hazards in dismantling electronic appliances by formal and informal recycling sectors in developing countries

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Abstract: The objectives of the research reported in this paper are to: 1) study the roles of formal and informal recycling sectors in developing countries in dismantling electronic appliances that have reached their end of life (EoL); 2) identify and evaluate the factors contributing to occupation hazards associated with dismantling of three computer electronics products: CRT monitor, CPU and PCB; 3) compare these factors (disassembly effort and ergonomic hazards) among the two sectors (formal or informal) in order to identify, which sector has high occupational hazards; 4) compare these factors among each other in order to find, if there is any correlation between them. The methodology adopted includes: data collection by interviewing dismantlers, video recording of dismantling processes, and identifying various dismantling processes involved in e-waste recycling in developing countries from literature and data analyses in order to assess and compare disassembly effort and ergonomic hazards.

Keywords: dismantling; disassembly effort; ergonomic hazards; EoL of electronic appliances; formal recycling sectors; informal recycling sectors.

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1 Introduction

As per the CPCB Guidelines (2008), '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". "It is a crisis not only of quantity but also a crisis born from toxic ingredients – such as the lead, beryllium, mercury, cadmium, and brominated flame retardants that pose both an occupational and environmental health threat" (Puckett et al., 2002).

Developed countries like the USA export 50% to 80% of e-waste collected to far off Asian countries for recycling. This percentage of e-waste exported is considered legal in the USA. "Although it has been a secret well-kept from most consumers, the export 'solution' has been a common practice for many years. But until now, nobody, not even many recyclers, seemed to know the Asian fate of these 'Made-in-USA' wastes, or what 'recycling' in Asia really looks like" (Puckett et al., 2002). The reasons behind their exports are the following:

1 it is expensive to recycle in developed countries
2 availability of cheap labour in developing countries
3 absence of import regulations (Khattar et al., 2007).

The imports are still being carried out, despite the fact that, it is illegal to import e-waste to India as India is a signatory to the Basel Convention for transboundary movement of hazardous substances (Khattar et al., 2007). Given these scenarios, an assessment was made of the existing practice in the e-waste management in India and it was identified that:

1 the amount of e-waste generated in the country is increasing to the extent that the volume might get doubled by the year 2013 to 2014
2 more recycling happens in informal sectors leading to uncontrolled release of toxic materials
3 there is a lack of environmentally sound recycling infrastructure in the country (CPCB Guidelines, 2008).

In India, e-waste recycling is handled by two main sectors, namely the formal and informal recycling sectors. The informal sector is well-networked and involves key players like vendors, scrap dealers, dismantlers and recyclers (Dwivedy and Mittal, 2012). "The formal sector is not well-networked but have contacts with large IT companies and organizations, from which they buy e-waste through tenders and auctions", as said by Mr. Jagadheesh, Techlogic recycling unit, Bangalore. "The formal sector is unable to grow to displace the informal sector due to lack of availability of e-waste for processing" (Ratnakar, 2010). Despite India generating about 3.5 lakh metric tonnes of e-waste and importing 50,000 metric tonnes of e-waste annually, the formal recycling sector is facing a tough competition from the informal sector for raw material (e-waste). This is because, "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 (Ratnakar, 2010). 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. "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" (Harivardhini and Chakrabarti, 2014).

In the study reported in this paper, disassembly effort and ergonomic hazards of dismantling processes carried out in both formal and informal sectors have been evaluated. The reasons behind this study are the following: while a large body of research exists in studying exposure hazards (due to toxic materials in e-waste) experienced by recyclers and dismantlers, relatively little research has been carried out in understanding and assessing the occupational hazards faced by dismantlers in e-waste dismantling sectors. This is in spite of the fact that general recycling scenario of developing countries is dominated by manual dismantling in crude working conditions, which lacks environmentally sound recycling infrastructure. These pose serious threats to the health of dismantlers when they continue to dismantle in the poor ergonomic postures. This can be evident from our earlier study (Harivardhini and Chakrabarti, 2014), in which it was found that "ergonomic risks associated with informal sector are more serious than those in the formal sector" and it also confirmed "besides exposure hazards and environmental hazards from hazardous substances handled while recycling in the informal sectors, ergonomic risks also pose serious threats to the health of dismantlers".

The effort taken to dismantle a unit has been evaluated by a disassembly effort index (DEI) model (Das et al., 2000); the ergonomic hazard associated with dismantling product units have been evaluated using MSD Risk Assessment Checklists (Washington State's WISHA Caution Zone and Washington State's WISHA Hazard Zone checklists, http://ergo-plus.com/ergonomic-assessments/). The disassembly effort and ergonomic hazards determined are then compared between formal and informal sectors to identify which sector has higher disassembly effort and occupational hazards and to find if there is any correlation between them. From the findings, the possible reasons for why a particular sector has higher disassembly effort and/or higher ergonomic hazards are then identified. Further, the paper discusses the peculiar roles played by, and relationships between, the formal and informal recycling sectors in developing countries like India, Africa and China, in dismantling e-wastes.

Section 2 elaborates on the roles played by formal and informal recycling sectors in dismantling various computer electronics products such as CRT monitor, CPU, PCB, keyboard, cables, etc. Each product's end of life (EoL) has been analysed to identify all the dismantling processes involved till the product reaches the recycling stage. Section 3 details the evaluation of disassembly efforts and ergonomic hazards for dismantling processes carried out on three products: CRT monitor, CPU and PCB. The results of evaluation are also tabulated. Section 4 elaborates on the results of comparison of the disassembly effort and ergonomic hazards involved in dismantling these three products for each sector and discussions on the results. Summary, conclusions and future work are discussed in Section 5.

2 The roles of formal and informal recycling sectors in the EoL phase of some computer electronics products

2.1 Laptop

Most laptops find their way to formal sectors. Keyboard, hard-drive, DVD drive, battery, mother board and some screws are dismantled. Those which are still in good working conditions are kept for reuse or refurbishment. Rest of the components are sold to recyclers for recycling. Tools which are used for laptop dismantling are screw drivers of four kinds (flat, T8 star bits, Philips 4.0 PH1 and 2.0 PH00) and tweezers. Usually five to six laptops are dismantled per day in the formal sector per operator.

2.2 Hard disk

Most hard disks are also dismantled in the formal sector. Parts retrieved from hard disks are: outer cover (plastic or metal), actuator, platter, retaining ring, metal plate beneath the actuator, and some screws. Most of the components find their way to metal and plastic recyclers. Common tools like screw drivers (flat or T8 star bits), circlip pliers, tweezers and chisel are used to dismantle hard disks. Twenty to 25 hard disks are dismantled per day per person in the formal sector.

2.3 CPU

CPUs find their way to both formal and informal sectors. In the formal sector, tools like screw drivers (flat or T8 star bits) are used to dismantle all components from the CPU. The outer metal cover goes to metal recyclers. Hard disks, mother board and power supply are kept for either reuse or recycling. Twenty CPUs are dismantled per day per operator in the formal sector.

Dismantling CPUs is quite common also in the informal sectors. But crude tools are used for dismantling, such as: screw drivers and iron hammer. Almost all components are retrieved either in their full form or in a damaged condition. Different techniques are used to recover copper from wires and cables inside the CPUs. Mother boards taken apart from these CPUs and are processed in various manner to recover the metals in them. More than hundred units are dismantled per day in the informal sector.

2.4 CRT monitor

Many of the CRT monitors find their way to informal sectors only. Dismantlers use crude tools like iron hammer and chisel to recover components from these. Copper from the CRT housing is recovered by different techniques such as: using blade/knife to cut and remove by bare hand; sometimes chisel and hammer are used to take copper out of the housings. Also, the cathode ray tube (CRT) retrieved from the monitors are crushed to pieces by a hammer. These pieces go for glass recycling or mostly get dumped in the landfills illegally. More than 50 units are dismantled per day in the informal sector.

CRT monitors are dismantled in the formal sector using tools like screw drivers, pliers and chisel. Components retrieved include side and front covers, whole plastic casing, CRT, connection wires, PCB, magnetic deflector and some screws. The CRT cables and connection wires are burnt by recyclers in order to recover copper from them in spite of the release of many toxic substances. Twenty units are dismantled per day in the formal sector.

2.5 PCB

In the formal sector, PCBs are dismantled to take out valuable components like RAM cards, processor, or heat sink. These components can either be reused or sold out to recyclers for high profit. Screw driver, pliers and chisel are the tools usually used for dismantling. After taking apart these components, the PCBs are sold out to recyclers.

These recyclers, with the help of dismantlers in the informal sector, dismantle the remaining components like transistors and other heat sinks on the board. The dismantling techniques they use are quite dangerous. Either the boards are heated in open space and then hammered to take apart the components, or chisel and hammer are used to remove the components. The workers are exposed to highly toxic substances while they heat the PCBs in an open space. The exposure hazards of these open heating of PCBs can be found in detail in Puckett et al. (2002).

3 Evaluation of disassembly effort and ergonomic hazards

In our earlier study (Harivardhini and Chakrabarti, 2014), evaluation was carried out in two scales:

1. to evaluate the effort taken to dismantle one unit (measured in terms of DEI)
2. to evaluate the effort taken to dismantle more than one unit (measured in terms of ergonomic hazards).

Former was evaluated by the DEI model and the later was evaluated by the risk assessment checklists (see Section 1). In the current study also, evaluation was carried out in a similar way (i.e., using the same two methodologies for the evaluation). It was assumed in our earlier study that only one factor (ergonomic risks) contributes to the occupational hazard faced by dismantlers. This was because of the following reason: DEI per unit calculated will contribute very less to the occupational hazards, since it is the effort taken to dismantle only one unit. Thus in the current study, DEI per day was calculated by multiplying, the number of units dismantled per day and the DEI per unit. In this way, DEI per day and ergonomic hazards per day were calculated for three products: CRT monitor, CPU and PCB, dismantled in both the sectors (formal and informal). And it is assumed that, these are the only two factors that could be the potential contributors of the occupational hazards faced by the dismantlers.

3.1 Data collection

Three products have been chosen: CRT monitor, CPU and PCB, for the following reasons:

1 Since consumption of these products is high in both developed and developing countries and since each of these contain a significant amount of precious metals, these products are the most frequently dismantled during EoL. Thus, studying the dismantling processes of these products will help understand the real occupational hazards faced by dismantlers.

2 Dismantling processes of these products have significant implications on both environment and economy, which are part of our future work.

The dismantling processes carried out on these products in both formal and informal sectors were collected in the form of videos. Five videos used in this study depict the real e-waste recycling scenarios prevailing in developing countries like Africa, China and India. The dismantling scenarios portrayed in other supporting documents (Puckett et al., 2002, 2005; Wath et al., 2010) which constitute studies on 'e-waste recycling in developing countries' match with the dismantling scenarios in the videos used. Thus, it can be claimed that the overwhelming dismantling scenarios countrywide in developing countries are those similar to the ones portrayed in the five videos used in this study. Among those five videos, four were taken from the literature and one was taken in a formal unit (Techlogic, Bangalore). All these four videos are investigative videos, filmed by established International Investigative Organizations: Basel Action Network (BAN), Greenpeace, ewasteguide. Also, they showcase the dismantling processes involved in e-wastes recycling, especially computer electronics products which were of our primary interest in this study.

3.1.1 CRT monitor

Videos of CRT monitor dismantling processes in formal and informal sectors are collected from literature.

3.1.2 CPU

Videos of CPU dismantling processes in formal and informal sectors are collected respectively from formal unit in Bangalore and literature.

3.1.3 PCB

Videos of PCB dismantling processes in formal and informal sectors are collected from literature.

3.2 Disassembly effort

Disassembly effort was evaluated by a DEI model developed by Das et al. (2000). This model was developed based on surveys carried out in a variety of commercial disassembly facilities. The DEI score calculated using this model is a representative of the total operating cost for disassembling a product. The major reasons behind selection of this model are the following:

1. it facilitates assessment of each step in an overall dismantling process
2. the model facilitates a comprehensive assessment of the disassembly effort expended by dismantlers as each dismantling step is evaluated against seven factors: time, tools, fixture, access, instruct, hazard and force
3. disassembly effort is obtained in terms of DEI (a quantitative score), which is useful in our work, since this index can be multiplied by the number of units dismantled per day in order to obtain DEI per day, which can then be compared with the ergonomic hazards faced by a dismantler per day
4. "The DEI score is used as an indicator for identifying the most difficult disassembly steps in a disassembly process" as found in our earlier work (Harivardhini and Chakrabarti, 2014).

3.2.1 Approach

Each dismantling step was evaluated based on seven factors (time, tools, fixture, access, instruction, hazard and force) on a cost/effort indexing scale and given a DEI score. The cost effort index scale is defined in the 0 to 100 range. This range is assigned on a weighted basis to each of the seven factors. Each factor has its own independent utility scale with assigned range as anchors. Evaluation of each step was carried out by choosing the appropriate anchors from the scoring card. The details required for choosing anchors for the factors time, tools, fixture and access were extracted directly from the video (see Table 1). But for other three factors (instruct, hazard and force), the values could not be directly identified from the video. Thus, the values were calculated depending on the given situation. The appropriate anchors for the factor instruct were determined as follows: training and group discussion for the formal sector and informal sector respectively. The appropriate anchors for the factor hazard were identified based on the necessity of wearing gloves, arm wrap/face mask, etc. The appropriate anchors for the factor force were derived from the kind of tools used in the dismantling process, e.g.: force is torsional for screw driver, leverage for pliers and chisel, and orthogonal or low impact for hammering.

In this way, each dismantling step was completely evaluated for all seven factors and given a total DEI score which is a summation of the individual DEI scores of the disassembly steps (Harivardhini and Chakrabarti, 2014).

Table 1 DEI score for CRT monitor

Formal unit location: Cape Town, South Africa

Source: 'E-waste: dismantling a CRT monitor', video by ewaste guide

Dismantling steps	*Time*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
Cut the main connection wires	10 s	Pliers	Two hands	Nil	Training	Gloves, face mask	Unfastening (leverage)	36
	2	4	6		10	2	12	
Removal of side cover by chiseling out	16 s	Chisel	Two hands	Nil	Training	Gloves, face mask	Unfastening (leverage)	37
	3	4	6		10	2	12	
Removal of whole plastic casing by unscrewing six screws	64 s	Screw driver	Two hands	Nil	Training	Gloves, face mask	Unfastening (torsional)	38
	12	4	6		10	2	4	
Equalise pressure in the CRT glass body: punch carefully a hole in to the CRT glass	18 s	Hammer and screw driver	Two hands	Nil	Training	Gloves, face mask	Unfastening (orthogonal)	31
	1	4	6		10	2	8	
Cut the connection wires inside the monitor using pliers	17 s	Pliers	Two hands	Nil	Training	Gloves, face mask	Unfastening (leverage)	37
	3	4	6		10	2	12	
Unscrew two screws to remove the PCB fixed at the base of the monitor	35 s	Screw driver	Two hands	Nil	Training	Gloves, face mask	Unfastening (torsional)	33
	7	4	6		10	2	4	
Removal of front plastic casing by unscrewing four screws	55 s	Screw driver and pliers	Two hands	Nil	Training	Gloves, face mask	Unfastening (torsional)	37
	11	4	6		10	2	4	
Removal of magnetic deflector yoke								
Assembly located on top of the CRT glass body by hand	11 s	Hand	One hand	Nil	Training	Gloves, face mask	Unfastening (torsional)	23
	2	2	3		10	2	4	

Total disassembly time = 3 min 57 s

Total DEI score = 272

Informal unit location: Ghana, West Africa

Source: 'How the west dump electronic waste in Africa and India', video by Greenpeace

Dismantling steps	*Time taken/unit*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
Breaking of a CRT monitor to remove mixed wires. plastic casing, CRT, PCB and deflector yoke assembly	5 mins	Iron hammer and chisel	One hand	Nil	Group discussion	Gloves, face mask/arm wrap, air supply and body suit	Unfastening (high impact)	67
	25	8	3		6	5	20	

Total disassembly time = 5 mins

Total DEI = 67

Disassembly time could not be derived directly. Details were observed carefully in the video to calculate time based on partial assumption.

Source: Adapted from Harivardhini and Chakrabarti (2014)

Table 2 DEI score for CPU

Formal unit location: Bangalore, India

Source: Video taken in Techlogic unit

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

Total disassembly time = 7 min 29 s

Total DEI score = 227

Informal unit location: Guiyu, China

Source: 'Exporting harm the high tech trashing of Asia', video by Basel Action (BAN)

Dismantling steps	*Time taken/unit*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
Removal of some screws	3 mins	Screw driver	Two hands	Nil	Group discussion	Gloves, face mask/arm wrap, air supply and body suit	Unfastening (low impact)	60
	23	4	6		6	5	16	
Removal of all mixed wires, metal casing, PCB and Other components	3 mins	Iron hammer	Two hands	Nil	Group discussion	Gloves, face mask/arm wrap, air supply and body suit	Unfastening (high impact)	68
	23	8	6		6	5	20	

Total disassembly time = 6 mins

Total DEI score = 128

Disassembly time could not be derived directly. Details were observed carefully in the video to calculate time based on partial assumption.

Table 3 DEI score for PCB

Formal unit location: Cape Town, South Africa								
Source: 'E-waste: dismantling a CRT monitor', video by ewasteguide								
Dismantling steps	*Time taken/unit*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
Removal of wires	44 s	Pliers	Two hands	Nil	Training	Gloves and face mask	Unfastening (leverage)	43
	9	4	6		10	2	12	
Removal of heat sinks and transistors	40 s	Screw driver	Two hands	Nil	Training	Gloves and face mask	Unfastening (torsional)	34
	8	4	6		10	2	4	
Removal of other components	61 s	Chisel	Two hands	Nil	Training	Gloves and face mask	Unfastening (leverage)	46
	12	4	6		10	2	12	
Total disassembly time = 2 mins 25s								
Total DEI score = 123								
Informal unit location: New Delhi, India								
Source: 'E-waste in India short documentary by Greenpeace'								
Dismantling steps	*Time taken/unit*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
PCB 1: Removal of transistors and capacitors from PCBs by heating and then hammering by a steel rod	2 mins	Pliers to hold and hammering by a steel rod	Two hands	Nil	Group discussion	Gloves, face mask and arm wrap, fire protection, air supply and body suit	Unfastening (low impact)	55
	18	4	6			5	16	
Total disassembly time = 2 mins								
Total DEI score = 55								
Informal unit location: New Delhi, India								
Source: 'E-waste in India short documentary by Greenpeace'								
Dismantling steps	*Time taken/unit*	*Tools*	*Fixture*	*Access*	*Instruct*	*Hazard*	*Force*	*DEI*
PCB 2: Removal of transistors and capacitors from PCB by using chisel and hammer along with a brick support	3 mins	Chisel and hammer	Two hands	Nil	Group discussion	Gloves and face mask	Unfastening (low impact)	57
	23	4	6		6	2	16	
Total disassembly time = 3 mins								
Total DEI score = 57								

Source: Harivardhini and Chakrabarti (2014)

Five videos showcasing the dismantling processes on three products in both the sectors were used in the DEI evaluation. Tables 1, 2 and 3 show the evaluation of DEI for the three products in each sector. The total DEI scores of each product in both sectors are also mentioned in the tables. Tables 1, 2 and 3 show the DEI scores computed in formal and informal sectors for three products: CRT monitor, CPU and PCB, respectively. Table 3 shows the DEI scores for dismantling PCB in two different methods namely:

1 heating and hammering the PCB to remove components

2 chiselling out the components by hammer
(result taken from Harivardhini and Chakrabarti, 2014).

3.3 Ergonomic hazards

The ergonomic hazards were identified by Washington State Ergonomic and MSD Risk Assessment checklists (Washington State's WISHA Caution Zone and Washington State's WISHA Hazard Zone checklists, http://ergo-plus.com/ergonomic-assessments/). "This tool is chosen because, it gives provisions for assessing not only how awkward sitting postures of dismantlers are, but also considers activities (such as repetitive hammering, chiseling, and screwing) and high hand force (such as gripping force), which are the primary dismantling activities associated with any disassembly processing" as mentioned by our earlier work (presented in Harivardhini and Chakrabarti, 2014).

3.3.1 Approach

Each body posture of the dismantler was assessed using two checklists: caution zone checklist and hazard zone checklist. The caution zone checklist is used as a screening tool. Each body movement is assessed for categories: awkward posture, high hand force, highly repetitive motion, repeated impact, awkward lifting and high arm vibration. If no positive findings can be identified, the job is regarded to be safe. Otherwise, a moderate risk is indicated and the job should be evaluated further using the hazard zone checklist. This checklist has the following categories: awkward posture, high hand force, highly repetitive motion, and repeated impact. Positive findings with the hazard zone checklist indicate that immediate actions are to be taken to reduce the risk (Health and Safety Blog, info@ergoplus.com; Harivardhini and Chakrabarti, 2014).

Disassembly processes, tools used, and body postures were extracted from the videos. Time duration of each posture was calculated based on the number of units dismantled by one dismantler in one day, as shown in Table 4. Gripping force for holding a screw driver was identified based on the work by Casey et al. (2002); according to their calculation, the average task grip force for holding a screw driver were in the range of 78 to 183 N, and peak task grip force were in the range of 141 to 306 N. These values are far greater than 10 pounds (44.5 N), the maximum value recommended in MSD checklists. In this way, each body movement is assessed for all categories in the checklists, for its ergonomic risks (Harivardhini and Chakrabarti, 2014).

Table 4 Ergonomic hazard for CRT monitor

Formal unit location: Cape Town, South Africa

Source: 'E-waste: dismantling a CRT monitor', video by ewasteguide

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 a CRT monitor	Screw drivers, pliers, hammer and chisel	1hr 20 mins	Working with the neck or back bent more than 30 degrees (without support and without the ability to vary posture) less than 2 hours total per day.	Nil	Nil
		52 mins	Gripping screw driver with a grip force greater than 10 pounds (equivalent to 44.5 N) for less than 2 hours total per day	Nil	Nil

Informal unit location: Ghana, West Africa

Source: 'How the west dump electronic waste in Africa and India', video by Greenpeace

Dismantling steps	*Tools used*	*Time taken for 50 units*	*Body movement while doing the task*	*Ergonomic hazard*	
				Caution zone	*Hazard zone*
Breaking of a CRT monitor to remove mixed wires. plastic casing, CRT, PCB and deflector yoke assembly	Iron hammer and chisel	4 hrs 10 mins	Using the same motion (hammering with forceful exertion on hand) with little variation every few seconds for more than 2 hours per day	Nil	Highly repetitive motion 14
		4 hrs 10 mins	Gripping hammer with a grip force greater than 10 pounds (equivalent to 44.5 N) for more than 4 hours total per day	Nil	High hand force 13
		4 hrs 10 mins	Working with the neck bent more than 45° (without support or the ability to vary posture) for more than 4 hrs total per day	Nil	Awkward posture 3
		4 hrs 10 mins	Working with the back bent forward more than 45° (without support or the ability to vary posture) for more than 2 hours total per day	Nil	Awkward posture 5

Table 5 Ergonomic hazards for CPU

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	4 hrs 40 mins	Working with the back bent more than 30 degrees forward (without support and without the ability to vary posture) more than 4 hours total per day.	Nil	Awkward posture 4
		2 hr 26mins	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

Informal unit location: Guiyu, China

Source: 'Exporting harm the high tech trashing of Asia', video by Basel Action (BAN)

Dismantling steps	*Tools used*	*Time taken for 100 units*	*Body movement while doing the task*	*Ergonomic hazard*	
				Caution zone	*Hazard zone*
Removal of all mixed wires, metal casing, PCB and other components	Iron hammer	5 hrs	Working with the back bent forward more than 30° (without support or the ability to vary posture) more than 4 hours per day	Nil	Awkward posture 4
		5 hrs	Using the same motion (hammering with forceful exertion on hand) with little variation every few seconds for more than 2 hours per day	Nil	Highly repetitive motion 14
Removal of some screws from CPU	Screw driver	5 hrs	Gripping screw driver with a grip force greater than 10 pounds (equivalent to 44.5 N) for more than 4 hours total per day	Nil	High hand force 13
		5 hrs	Working with the neck bent more than 45° (without support or the ability to vary posture) for more than 4 hrs total per day	Nil	Awkward posture 3
		5 hrs	Working with the back bent forward more than 45° (without support or the ability to vary posture) for more than 2 hours total per day	Nil	Awkward posture 5

Source: Harivardhini and Chakrabarti (2014)

Table 6 Ergonomic hazard for PCB

Formal unit location: Cape Town, South Africa					
Source: 'E-waste: dismantling a CRT monitor', video by ewasteguide					
Dismantling steps	*Tools used*	*Time taken for 20 units*	*Body movement while doing the task*	*Ergonomic hazard*	
				Caution zone	*Hazard zone*
Removal of wires, heat sinks, transistors and other components	Screw driver, pliers and chisel	48 mins	Working with the neck or back bent more than 30 degrees (without support and without the ability to vary posture) less than 2 hours total per day.	Nil	Nil
Informal unit location: New Delhi, India					
Source: 'E-waste in India short documentary by Greenpeace'					
Dismantling steps	*Tools used*	*Time taken for 250 units*	*Body movement while doing the task*	*Ergonomic hazard*	
				Caution zone	*Hazard zone*
PCB 1: Removal of transistors and capacitors from PCBs by heating and then hammering by a steel rod	Pliers to hold, hammering by a steel rod	4 hrs 17 mins	Working with the back bent forward more than 30° (without support or the ability to vary posture) more than 4 hours per day	Nil	Awkward posture 4
		4 hrs 17 mins	Gripping pliers with a hand force of 10 lb more than 4 hours per day	Nil	High hand force 13
		4 hrs 17 mins	Using the same motion (hammering by a steel rod) with little variation every few seconds for more than 2 hours per day	Nil	Highly repetitive motion 14
Informal unit location: New Delhi, India					
Source: 'E-waste in India short documentary by Greenpeace'					
Dismantling process for recycling	*Tools used*	*Time taken for 100 units*	*Body movement while doing the task*	*Ergonomic hazard*	
				Caution zone	*Hazard zone*
PCB 2: Removal of transistors and capacitors from PCBs by using chisel and hammer along with a brick support	Chisel and hammer	5 hrs	Working with the back bent forward more than 30° (without support or the ability to vary posture) more than 4 hours per day	Nil	Awkward posture 4
		5 hrs	Holding chisel with a hand force of 10 lb more than 4 hours per day	Nil	High hand force 12
		5 hrs	Using the same motion (hammering with forceful exertion on hand) with little variation every few seconds for more than 2 hours per day	Nil	Highly repetitive motion 14

Source: Harivardhini and Chakrabarti (2014)

The same five videos, which are used for DEI evaluation, are also used for evaluating ergonomic hazards. Tables 4, 5 and 6 show the evaluation of ergonomic hazards for the three products in each sector. Tables 4, 5 (formal unit result taken from Harivardhini and Chakrabarti, 2014) and 6 show the ergonomic hazards encountered in formal and informal sectors respectively for three products: CRT monitor, CPU and PCB. Table 6 shows the ergonomic hazard associated with dismantling PCB in two different methods namely:

1. heating and hammering the PCB to remove components (result taken from Harivardhini and Chakrabarti, 2014)
2. chiselling out the components by hammer (result taken from Harivardhini and Chakrabarti, 2014).

4 Results and major findings

4.1 Results

The study reported above, which details the assessment of DEI and ergonomic hazard for three products: CRT monitor, CPU and PCB, was carried out in order to identify the occupational hazard scenarios of two sectors namely: formal and informal sectors in developing countries. It is a common assumption that 'formal/organised recycling sectors have relatively less occupational hazard than do the informal/unorganised recycling sectors'. In this study, we have also attempted to verify this hypothesis.

Figure 1 Comparison of DEIs per unit dismantled among formal and informal sectors (see online version for colours)

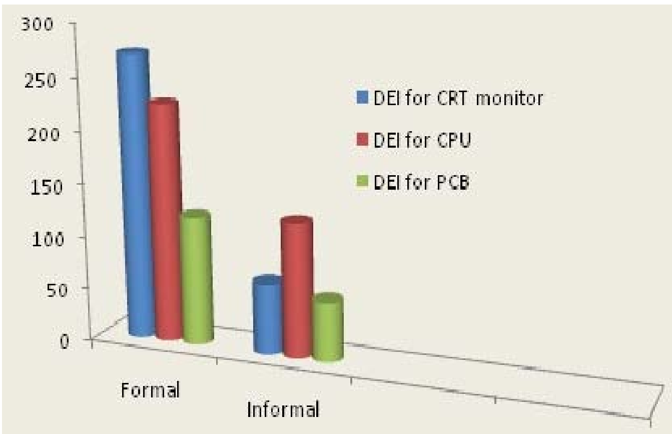


Table 7 compares the DEI and ergonomic hazards in both the sectors for the three products. In order to quantify ergonomic hazards, three different ratings have been given for three categories of ergonomic hazard, over a scale of 0-1. The ratings are 0, 0.5 and 1 for:

1 no hazard

2 caution zone

3 hazard zone categories, respectively.

If all units dismantled in a given period of time (e.g., one day) have high hazard in every possible hazard category, say: awkward posture, high hand force and highly repetitive motion, then the scores for all the three hazards are aggregated and given as total hazard zone score (e.g., 3 in the example case).

The DEI and ergonomic hazards identified for the three products dismantled in both formal and informal sectors are compared in Figures 1 to 4.

Figure 2 Comparison of DEIs per unit dismantled for the three products (see online version for colours)

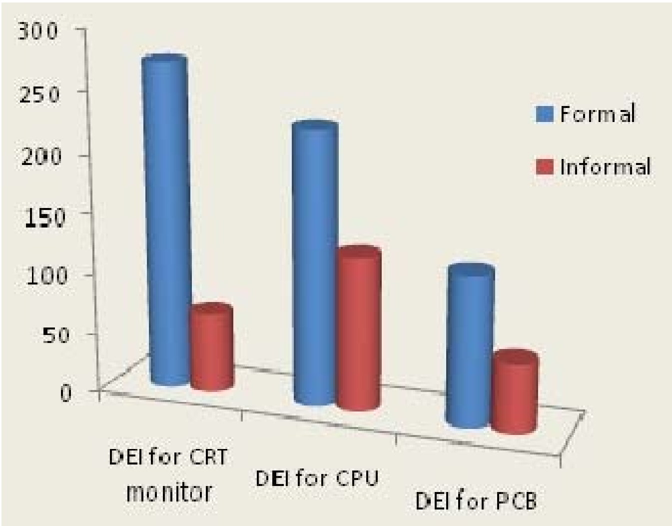


Figure 3 Comparison of ergonomic hazards per day among formal and informal sectors (see online version for colours)

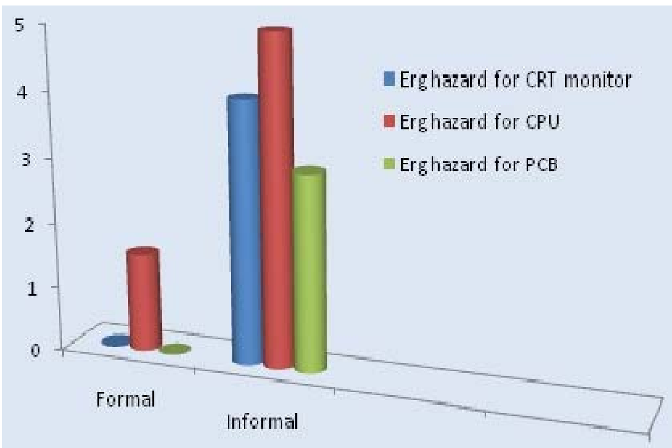
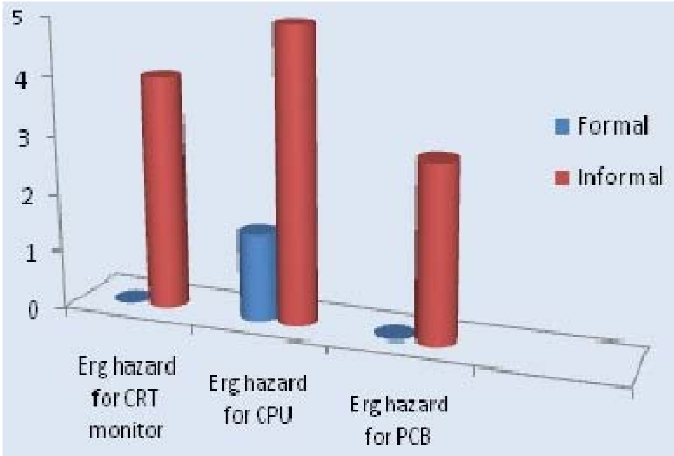


Figure 4 Comparison of ergonomic hazards per day of three products (see online version for colours)



The following results have been obtained above:

1 In the formal sector, out of the three products, dismantling of CRT monitor has the highest DEI score per unit dismantled, followed by the DEI scores of CPU and PCB respectively. However, in the informal sector, dismantling of CPU has the highest DEI score, followed by the DEI scores of CRT monitor and PCB respectively (see Figure 1).

2 For all three products: CRT monitor, CPU and PCB, the DEI scores per unit dismantled seems to be higher in the formal sector than in the informal sector (see Figure 2). The reason for the above seems to be the following. Dismantlers in the formal sector segregate many more materials than they do in the informal sector – leading to a larger number of dismantling steps. Further dismantlers in the formal sector use appropriate dismantling techniques to carefully separate parts. Care is taken to ensure that the parts are retrieved without causing major damage to them. This is achieved with the help of a wider variety of dismantling tools than used in the informal sector. For the same amount of, or slightly less, time, dismantlers in the informal sector use crude tools for dismantling. Care is not taken to retain the part shape. The advantages of the dismantling processes carried out by the formal sector are not only segregation of a larger number of materials, but also achievement of higher purity in the recycled material. Further, the parts and materials taken apart have the option for other recovery options like reuse or refurbishing.

3 From the ergonomic hazards results, it was found that, dismantling of CPU has the highest ergonomic hazard score (per day) in both formal and informal sectors. Dismantling of CRT monitor has the second highest score, followed by hazard scores of PCB in both the sectors (Figure 3).

4 For all three products, the DEI scores per unit dismantled were found to be lower in the informal sector than in the formal sector (Figure 3). However, for all three products, ergonomic hazards per day were much higher in the informal sector than in the formal sector (see Table 7). This is because, dismantlers in the informal sector

worked continuously (dismantling 100 units or more of any product per day) for four to eight hours sitting in awkward postures and repeating the same task which required high hand force. In contrast, dismantlers in the formal sector worked for two hours or less per day (dismantling not more than 20 units per day).

5 In order to compare DEI and hazard information in an equitable manner, unit scores for DEI are multiplied by the number of units dismantled per day, and the aggregated DEI scores are compared with hazard scores, see Table 7. The comparison shows the following:

- There is an interesting anomaly. For instance, for CRT monitor, aggregated DEI score is higher in the formal than in the informal sector, but while there is no ergonomic hazard in the formal sector, the ergonomic hazard in the informal sector is high (see Table 7). The reason behind this is that the dismantler in this sector dismantled the CRT monitor by standing with only his neck bent forward. Even if he were to dismantle 50 CRT monitors in a similar posture (with neck bent by more than 30 degrees while exerting a grip force over 10 pounds), the scores would still fall only in caution zone and not in hazard zone.
- Thus, from the above, it can be concluded that, while higher aggregated DEI (i.e., effort in dismantling per day) will generally correlate with higher ergonomic hazards (per day), there can be specific instances where effort applied, while higher, would still be mundane as long as the postures were well-maintained, leading to less ergonomic hazards, and vice-versa.

6 Aggregated DEI scores per day on average is much higher (9,967) in the informal sector than in the formal sector (4,147). Also, hazard scores on average are similarly higher: 4 for informal sector as opposed to 1.5 for the formal sector.

4.2 Major findings

1 Two potential factors (DEI and ergonomic hazards) are identified to contribute to the occupational hazards (physical not exposure hazards). Assessment of the two factors was carried out for three products (CRT monitor, CPU and PCB) in both the formal and informal sectors and the results tabulated.

2 Correlation between these two factors was studied and it was identified that they need not correlate in all instances (see Section 4.1, point 5).

3 Both average DEI and average ergonomic hazards for the same set of products dismantled per day are higher in informal sectors than in formal sectors (see Section 4.1, point 4).

4 Another finding is that DEI per product is higher (for all three products) in the formal sector than those observed in the informal sector (see Table 7). Some of the possible reasons for this trend are outlined (refer Section 4.1, point 2).

5 Ergonomic hazards per day are much higher in the informal sector than in the formal sector for all three products (see Table 7). Some of the possible reasons for this trend are outlined (refer Section 4, point 4).

Table 7 Comparison of DEIs and ergonomic hazards among formal and informal sectors

Products dismantled	*Formal*					*Informal*				
	DEI score		*Ergonomic hazards*			*DEI score*		*Ergonomic hazards*		
	DEI score per unit	*DEI score per day*	*Caution zone*	*Hazard zone*	*Ergonomic hazards per day*	*DEI score per unit*	*DEI score per day*	*Caution zone*	*Hazard zone*	*Ergonomic hazards per day*
CRT monitor	272	5,440	0	0	0	67	3,350	0	4	4
CPU	227	4,540	0.5	1	1.5	128	12,800	0	5	5
PCB	123	2,460	0	0	0	57 (PCB 1)	5,700	0	3	33
						55 (PCB 2)	13,750	0	3	
		Average: 4,147			Average: 1.5		Average: 9,967			Average: 4

5 Summary, conclusions and future work

The study reported here gives an insight into the occupation hazard faced by the dismantlers in two sectors: formal and informal sectors in developing countries. The roles of these sectors and the relationships between them, when dealing with e-waste recycling, have been discussed for a number of electronic appliances. Two potential factors such as DEI and ergonomic hazards have been identified to contribute to the occupational hazards. Assessment of DEI and ergonomic hazards for three products has been carried out to understand the effort and ergonomic quality of dismantling processes carried out in the two sectors and the results are tabulated. DEI and ergonomic hazards associated with the two sectors are compared with each other to:

1 test the hypothesis: 'Formal/organised recycling sectors have relatively less occupational hazard than do informal/unorganised recycling sectors'

2 find out if there is any correlation exists between these two factors.

Findings from the empirical data led to the following major conclusions:

1 Two potential factors (DEI per day and ergonomic hazards per day) are identified as contributing to occupational hazards (physical not exposure hazards) and are assessed. Correlation between these two factors was sought. It was found that the factors do not correlate with one another. This led to the conclusion that, DEI or Ergonomic hazard, taken individually, provides only a part of the picture of what constitutes occupational hazards in disassembly. Both must be taken together to obtain the complete picture of occupational hazards.

2 The hypothesis 'Formal/organised recycling sectors have relatively less occupational hazards than do Informal/unorganised recycling sectors' has been verified, with data from the dismantling processes for three computer electronics products in real recycling scenarios in developing countries. It has been found that the formal sector has less occupational hazards than do the informal sector, as evidenced by the fact that both average DEI and average ergonomic hazards for the same set of products per day are higher in informal sectors than in formal sectors.

A crucial observation is that the number of products dismantled per day is much higher in informal sectors than in formal sectors, while the level of dismantling (number of different dismantling steps) is less in informal sectors. This appears to be linked to economic parameters which have not been considered in this paper. Further, this kind of dismantling in informal sectors has environmental implications, since parts not disassembled further are dumped into the environment. This factor also needs further investigation.

Future work, therefore, will focus on exploration of economic and environmental factors in relations to the effort and ergonomic factors explored in this paper, so as to see the overall picture of the dynamics of dismantling in these sectors.

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