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ANALYSIS OF DISMANTLING PROCESSES FOR ASSESSING DISASSEMBLY EFFORT AND ERGONOMIC HAZARDS AT THE END OF LIFE OF ELECTRONIC APPLIANCES

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ABSTRACT

The objectives of the research proposed in this paper are to: (i) review the state of art of various operations carried out during e-waste dismantling processes including dismantling equipment used and dismantling issues encountered in informal sector and formal sector, (ii) identify dismantling processes encountered during recycling and reuse of electronic appliances, and (iii) assess their associated disassembly effort and ergonomic hazards. The methodology adopted includes: data collection by interviewing dismantlers, video recording of dismantling processes, and identifying various dismantling issues and dismantling processes involved in recycling from the Literature and data analysis to assess disassembly effort and ergonomic hazards of the dismantling processes identified. Disassembly effort was measured in terms of Disassembly Effort Index (DEI) using a DEI model, and ergonomic hazards were assessed by an MSD Risk Assessment Checklist tool. Evaluation of DEI and ergonomic hazards was carried out on various electronic appliances that have reached their End of Life (EoL). Results of evaluation are tabulated. Some of the most difficult disassembly steps and ergonomic risks associated with both formal and informal sectors were identified. It was found that there is a correlation between the number of disassembly steps and the Total DEI score. Also, the results on ergonomic risks found from the study showed that the ergonomic risks associated with informal sector are more serious than those in the formal sector. These include awkward postures, high hand forces and highly repetitive motions.

Keywords: disassembly effort index (DEI), ergonomic risks, disassembly process plan (DPP), end of life (EoL) phase.

INTRODUCTION

In order to reduce its environment and health impacts, electronic waste (e-waste) containing hazardous substances and precious metals should be treated and disposed in an environmentally friendly manner. This will help in improving environmental sustainability. A wide variety of electronic devices ranging from mobile phones to PCs becomes indispensable in daily life across the world. These devices are ultimately disposed as e-waste at their EoL phase. "Rapid growth of electronic industry combined with rapid product obsolescence results in discarded electronics which is now the fastest growing waste stream in the industrialized world" [1]. Management of e-waste involves a multidisciplinary approach. There is no standard methodology developed till now for efficient management of e-waste [1]. It is found difficult to treat e-waste in an efficient manner both financially and environmentally, because of its complex structure, intricate parts, uncertain returns and no systematic planning of the EoL treatment processes. "The various items found in e-waste in different range make them more diverse and complex in nature" [2]. How to preserve natural resources by closing the product life cycle loop is still a big question in various research areas. One way of addressing this is by reuse, remanufacture, or recycling of products. "…To close the cycle, disassembly and recycling of products became a new challenge for the producing industry" [3].

The manner of recycling in developing countries like Asia and Africa is often harmful to the environment and is dangerous for the people involved in the informal recycling business [4] and is significantly less efficient than that in Europe since retrievable metals are still being lost [5]. In developing countries, informal recycling is carried out by poor and marginalized social groups who resort to scavenging for income generation or survival [6]."In absence of adequate technologies and equipment, most of the techniques used for the recycling/treatments of E-waste are very raw and dangerous"; "Most of the time, dismantling and recycling operations are performed by workers without appropriate Personnel Protection Equipment" ([7] as mentioned in [1]). In absence of suitable techniques and infrastructure, the workers in such areas are prone to serious occupational health hazards [8]. Also it was observed that these dismantling and recycling areas are without any proper lighting and ventilation [1].
Researchers [9, 10, 1, 11] have studied the potential environmental and occupational hazards associated with these informal recycling processes carried out in developing countries. Environmental hazards include heavy metals leaching in to ground water, and emission of dioxins and hydrocarbon in to air, water and soil. Occupational hazards include toxicity to workers and nearby residents from tin, lead, brominated dioxin, beryllium, cadmium, mercury inhalation, etc. The occupational hazards listed in their work also include the worker's exposure to various hazardous substances handled during recycling processes and their subsequent health impacts.

There seems to have been no study that focused on the occupational hazards arising from manual dismantling processes, in spite of the fact that these dismantling processes are mandatory for any e-waste recycling. Especially in developing countries, dismantling is an integral part of recycling. 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, e.g. awkward sitting postures, repetitive actions like hammering and chiseling, gripping dismantling tools for a long time, etc.

This research work, therefore, focuses on the disassembly effort encountered in two important recycling scenarios: 1) informal and 2) formal recycling sectors, and in two scales: 1) to evaluate the effort taken to dismantle one unit and 2) to evaluate the effort taken to dismantle more than one unit. The effort taken to dismantle one unit was evaluated by a DEI model; the effort taken to dismantle more than one unit was evaluated by MSD Risk Assessment Checklists. The work is reported as follows: Section 2 highlights the various methods available to quantify disassembly effort and ergonomic hazards, Section 3 discusses the dismantling processes used in informal and formal recycling sectors, Section 4 explains in detail the processes of evaluation of disassembly effort and ergonomic hazards of dismantling processes, and Section 5 discusses results and inferences; conclusions are discussed in Section 6.

LITERATURE REVIEW

DISASSEMBLABILITY EVALUATION

Few researchers have emphasized the importance of addressing disassembly effort and difficulty issues during the design stage of products, in order to improve disassemblability of products at their EoL phase. They have developed methods that help in quantifying disassembly effort. Kroll and Hanft [12] developed a method to evaluate ease of disassembly of products by assigning task difficulty scores to disassembly tasks. These scores were derived from work-measurement analyses of standard disassembly tasks. These scores are then used to identify weaknesses in the design, and to compare alternatives quantitatively. Sodhi *et al*., [13] developed an unfastening effort analysis (U-effort) model, which helps designers to evaluate and select their fastener options. For each fastener type, the model identifies several causal attributes, and uses these to derive the U-effort index for a given case. It can also be used to calculate disassembly time. Hitachi Disassemblability Evaluation Method (DEM) is a method developed in 1993 for quantitative evaluation of the difficulty level associated with disassemblability of a new product. This DEM score acts as an index for both ease of disassembly and to indicate areas which require design improvements [14]. Das *et al*., [15] developed a multi-factor model to compute a disassembly effort index (DEI) score based on seven factors, i.e. time, tools, fixture, access, instruct, hazard and force. Using a conversion scale, the DEI score is used to derive an estimate of disassembly cost and disassembly return on investment. Since the work reported in this paper focuses on identifying the most difficult disassembly steps of an overall disassembly process, and the factors which contribute to disassembly difficulty, the DEI model has been used to evaluate disassembly processes.

To quantify disassembly time, several methods are available. For instance, Yi *et al*., [16] proposed a method for disassembly time evaluation considering type, size, weight, and connection parts of the product. Desai and Mital [17] developed a methodology which assigns time-based numeric indices to each design factor, from which disassembly time could be determined easily. A higher score indicates anomalies in product design from the disassembly perspective. Disassemblability of a product could be increased by addressing these anomalies. Gungor and Gupta [18] developed a methodology for measuring efficiency of a disassembly sequence by determining disassembly time, disassembly directions, number of components, and joint types.

A number of methods have been reported that use various indices to evaluate disassemblability. Suga *et al*., [19] proposed an approach for evaluation of disassemblability by introducing two parameters (energy for disassembly and entropy for disassembly) that describe disassemblability quantitatively. Veerakamolmal and Gupta [20] developed a technique to analyze efficiency of designing electronic products for environment. The efficiency of each design is indicated using a Design for Disassembly Index (DfDI). DfDI uses a disassembly tree which relies on the product's bill of materials. This index can be used to compare alternative designs using efficiency as the criterion. Chen [21] developed a method with which an evaluation score for ease of both disassembly and recycling can be generated by using axiomatic design.Wang and Allada [22] developed a quantitative methodology for serviceability evaluation by calculating disassembly, reassembly and handling indices through a fuzzy neural network model.

ERGONOMIC HAZARD EVALUATION TOOLS

RULA (Rapid Upper Limb Assessment tool) was developed by Atamney and Corlett in1993.It is best for seated tasks. The final risk assessment score combines arm/wrist risk with neck, trunk and leg risk. It also gives suggestions as to whether changes are required or not required in the process used in the tasks. A limitation is that it is weak in determining risk due to repetition [23].

REBA (Rapid Entire Body Assessment tool) was developed by Hignett and Atamney in 2000. It is a better tool for assessing whole body posture, such as static, dynamic, unstable or rapidly changing postures. REBA score can be associated with risk level, where each risk level has its own action requirement. A limitation is that it is not very useful for production line work. Also, neither of these tools is suitable for assessing ergonomic activities associated with disassembly processing [24].

Washington State Ergonomic and MSD Risk Assessment checklists were developed to evaluate ergonomic risk factors of any job. In our work, these checklists were used to assess occupational hazards arising from poor ergonomic activities of dismantlers. 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, screwing) and high hand force (such as gripping force), which are the primary dismantling activities associated with any disassembly processing [25].

There are other tools such as Liberty Mutual tables [26] for assessing lifting, carrying, pushing and pulling tasks. It is also known as Snook tables. For assessing manual lifting and lowering tasks, Lifting calculator [27] developed by Washington State Department of Labor and Industries can be used.

DISMANTLING PROCESSES IN INFORMAL AND FORMAL RECYCLING SECTORS

The details of recycling sectors, dismantling equipment used and some of the dismantling issues encountered in both informal and formal sectors were collected from literature and two dismantling units (Eco-bird recycling unit and Techlogic recycling unit, Bangalore).

INFORMAL RECYCLING SECTOR

The informal sector is well-networked and it involves key players like vendors, scrap dealers, dismantlers and the recyclers [28]. In the cities, India's poor scrape a living by breaking down PCs and monitors.

A survey by e-parisara (an authorized recycling unit in Bangalore) has shown that 90 per cent of e-waste is still going into the informal sector. VeerendraKaur, marketing head at e-parisara says “these informal sectors are not equipped to handle this kind of material in a scientific manner”. “Besides being highly polluting, the informal recycling also impacts those who manually dismantle the waste without proper equipment”, as mentioned by an official from the Karnataka State Pollution Control Board (KSPCB) [29].

DISMANTLING EQUIPMENT

Mostly hammers, chisels, hand drills, cutters, electric torch/burners, wire clippers, wire cutters and some time electric drills are used for dismantling the WEEE [7]. In some recycling units in New Delhi, Choppers are used to chop computer batteries which primarily contain hazardous cadmium. Workers hold mother boards with a support of a brick as shown in Figure-1 and dismantle components using hammer and chisel.

Figure-1. Worker dismantling PCB mother board with chisel and hammer (video by Green Peace [30]).

DISMANTLING ISSUES

Very often child labour is employed to separate parts from the mother boards using tools like wire cutters and pliers [9].

Main parts of the computers such as monitors, key boards, mother boards, casing, processors etc are separated by bare hands without any disassembly tools [9].

“Lack of systematic planning of disassembly of worn-out electronic products leads to costly inefficient recycling” [3]. This is predominantly the situation in informal sectors.

FORMAL RECYCLING SECTOR

Authorized e-waste recycling facilities in India capture only 3% of the total e-waste generated; the rest makes its way to informal recycling yards in major cities [31]. Despite of the fact that there are 27 authorized recycling sectors in Bangalore, Bangalore is fast on its way to becoming a “dumping ground” for e-waste generated by the industry. A report released by IT trade body ASSOCHAM has estimated that overall quantum of e-waste generated in Bangalore as 18,000 tonnes a year, growing at a compounded rate of 20 percent a year [29]. In Delhi, there are nine authorized collectors and segregators of e-waste. Delhi government has once again appealed to consumers to dispose of e-waste only through authorized

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recyclers but these authorized sectors are not able to succeed because of reasons like: there is a massive lack of understanding of recent e-waste disposal rules and waste-pickers succeed in this business since they have a direct approach to consumers unlike authorized recyclers [32].

DISMANTLING EQUIPMENT

A clamp attached with a rotating handle to hold the mother board and hammer it to dismantle small components soldered to it. Screw drivers, chisels, cutting blades, nose pliers, star bits screw driver, flat bits screw driver, drilling machine, cutting machine, powered drills are the primary dismantling tools used. Hammer is the main dismantling tool in few authorized units. Other auxiliary equipment include: wooden table for dismantling attached with a bag filter (dust collector) that is further connected to a chimney, labeled containers to store segregated e-waste, safety equipment including gloves, face mask, goggles and helmet.

DISMANTLING ISSUES

- Dismantlers are not trained but they have learnt the techniques on their own. If they encounter unfamiliar products, then they will follow trial and error method in using the dismantling tools to dismantle them (example:
- Mac star PC hard disk made in 1940, having 140 MB storage capacity is very old, dismantlers tried various tools and found star screw driver as the best dismantling tool for removing only the lids, they were waiting for other surprises inside the hard disk).
- Dismantlers find difficulty in using automated tools because they are not comfortable in using them since they have to take extra care while handling them and lack of knowledge in using them.
- Different connections and assemblies in a single product cause frequent change of tools. This leads to increasing dismantling time.
- Rivets (in UPS and other instruments) are removed by gas cutting with lot of difficulties.
- Molded connections in silicon circuits are difficult to separate since these cannot be heated as well due to probable risk of explosion.
- Last feasible option for any dismantling process is the usage of hammer to carry out destructive disassembly. However, repetitive usage of hammer for destructive disassembly of circuit boards and other computer parts are not efficient for further recycling process.
- Almost all products which they receive do not have labels explaining how to dismantle or how to handle them in their EoL, No labeling results in long dismantling time to dismantle buttons and connections.

EVALUATION OF DISASSEMBLY EFFORT AND ERGONOMIC HAZARDS

DISASSEMBLY EFFORT

Disassembly effort was measured in terms of the Disassembly effort index (DEI), which was calculated using a multi-factor DEI model as mentioned earlier. This model was developed based on surveys carried out in a variety of commercial disassembly facilities. This model was developed to support and facilitate economic analysis of a disassembly activity. The DEI score calculated using this model is a representative of the total operating cost for disassembling a product. In our work, however, the DEI score is used as an indicator for identifying the most difficult disassembly steps in a disassembly process.

MATERIALS AND METHODS

DEI model can be used effectively for any manual disassembly process. It works on the basic assumption that “Disassembly is a multi-step process and it can be represented by a Disassembly Process Plan (DPP)”. A DPP is described by a sequence of processing steps that are needed for removing or separating fasteners, parts and subassemblies from the product in order to accomplish complete disassembly of the product. There could be many DPPs for a single product, since a product could be disassembled in many ways. For our work, DPPs were derived from videos collected from literature and from dismantling units. Each video showcases a complete dismantling process of one product that has reached its EoL. Four videos were collected from the literature showcasing three different dismantling scenarios namely: for formal recycling sector, informal recycling sector and dismantling by a trained individual. Screenshots from two videos showing the dismantling steps of a Hard disk and a CRT monitor in a formal recycling sector are shown in Figure-2 and Figure-3. Screenshot from one video showing two different types of dismantling processes carried out for Printed Circuit Board (PCB) in an informal recycling sector are shown in Figure-1 and Figure-5. Screenshot from one video showing a dismantling process of a Mobile phone Printed Wiring Board (PWB) by a trained individual is shown in Figure-4. It was observed that the dismantling processes carried out in the informal sector are mostly destructive. This is because these dismantled products go for recycling and it is not necessary to retain their product structure. But those in the formal sector are mostly non-destructive processes, since some parts that are in working condition go for reuse and the rest are recycled as shown in Table-1.

These videos portray dismantling processes of existing products. Thus, it is possible to derive only one DPP for each product from the video. It should also be noted that this DPP might or might not be the Best Disassembly Process Plan (BDPP). Each step of a DPP 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.

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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 either the video or from the DPP. Thus the values were calculated depending on the given situation. It was determined that the appropriate anchors for the factor instruct were training, group discussion and time range for the worker to assess the next step is >30 seconds for the formal unit, informal unit and trained individual, 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 DPP for a product 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.

Figure-2. Dismantling of Hard disk - chiseling out the outer lid with chisel (video by e-waste guide [33]).

Figure-3. Dismantling of CRT monitor (video by e-waste guide [34]).

Figure-4. Dismantling of mobile phone PWB (video by Gold-N-Scrap [35]).

ERGONOMIC HAZARDS

Occupational hazard, as discussed in this work, includes only ergonomic hazard (such as using awkward postures, high hand force, and highly repetitive motion as encountered by dismantlers while they dismantle for a long duration of time). The hazards are identified by Washington State Ergonomic and MSD Risk Assessment checklists as mentioned earlier.

MATERIALS AND METHODS

Two videos from dismantling unit and one video from literature were collected. These videos showcased two different dismantling scenarios: for formal recycling sector and for informal recycling sector. These videos show the body postures of dismantlers while they carried out complete dismantling processes of a CPU and Hard disk, as shown in Figure-6, and two different dismantling processes of PCB, as shown in Figure-1 and Figure-5. 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 [36].

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., [37]; 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.

Figure-5. Dismantling of PCB by heating and then hammering by a steel rod (video by Green Peace [30]).

Figure-6. Dismantling of CPU and Hard disk (video taken in Techlogic dismantling unit, Bangalore).

RESULTS AND INFERENCES

The results of DEI evaluation and ergonomic hazard assessment for some of the products (CRT monitor, PCB, Mobile phone PWB, CPU and Hard disk) are shown in Table 1-7.

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Table-1. DEI table - CRT monitor (Formal unit).

Dismantling steps for Re-use/Recycling	Time	Tools	Fixture	Access	Instruct	Hazard	Force	DEI
Cut the main connection wires	10s 2	Pliers 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (leverage) 12	36
Removal of side cover by chiselling out	16s 3	Chisel 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (leverage) 12	37
Removal of whole plastic casing by unscrewing 6 screws	64s 12	Screw driver 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	38
Equalize pressure in the CRT glass body: Punch carefully a hole in to the CRT glass	18s 1	Hammer and screw driver 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (orthogonal) 8	31
Cut the connection wires inside the monitor using pliers	17s 3	Pliers 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (leverage) 12	37
Unscrew 2 screws to remove the small PCB fixed at the base of the monitor	35s 7	screw driver 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	33
Removal of front plastic casing by unscrewing 4 screws	55s 11	Screw driver and pliers 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	37
Removal of magnetic deflector located on top of the CRT glass body by hand	11s 2	Hand 2	One hand 3	None 0	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	23
Removal of wires from PCB	55s 11	Pliers 4	Two hands6	None 0	Training 10	Gloves, face mask 2	Unfastening (leverage)12	45
Removal of capacitors from PCB by unscrewing 1 screw	34s 7	Screw driver 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (torsional) 4	33
Chiselling out the capacitors from PCB	61 11	Chisel 4	Two hands 6	None 0	Training 10	Gloves, face mask 2	Unfastening (leverage) 12	45
Total disassembly time = 6min 27s Total DEI score = 395	Source: Dismantling a CRT monitor video by e-waste guide [34]							

Table-2. DEI table - printed circuit boards (PCBs) (Informal unit).

Dismantling steps for Recycling	Time taken / unit	Tools	Fixture	Access	Instruct	Hazard	Force	DEI
Removal of transistors and capacitors from PCB by usingchisel and hammer along with a brick supportas shown in the Figure-1.	3mins 23	Chisel and Hammer 4	Two hands 6	None 0	Group discussion 6	Gloves and face mask 2	Unfastenin g (Low impact) 16	57
Total disassembly time = 3 min Total DEI score = 57	Source: E-waste in India - a short documentary by Green Peace [30]							

Table-3. DEI table - mobile phone PWB (Trained individual).

Dismantling steps for recycling	Time taken/ unit	Tools	Fixture	Access	Instruct	Hazard	Force	DEI
Removal of keypad sticker	6s 0	Hand 2	One hand 3	None 0	>30s 4	Gloves + face mask 2	2 lb 0	11
Removal of screen	9s 1	Chisel 4	One hand 3	None 0	>30s 4	Gloves + face mask 2	6lb 3	17
Removal of parts and connection pins from PWB	56s 11	Pliers 4	One hand 3	None 0	>30s 4	Gloves + face mask 2	Unfastening (Leverage) 12	36
Total disassembly time = 1 min 11s Total DEI score = 64	Source: E-waste in India - a video by Gold-N-Scrap [35]							

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Table-4. Occupational hazard - printed circuit boards (PCBs) (Informal unit).

Dismantling steps for recycling	Tools used	Time taken for 250 units	Body movement while doing the task	Ergonomic hazard	
				Caution Zone	Hazard Zone
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
Source: E-waste in India - a short documentary by Green Peace [30]					

Table-5. Occupational hazard - printed circuit boards (PCBs) (Informal unit).

Dismantling steps for recycling	Tools used	Time taken for 100 units	Body movement while doing the task	Ergonomic hazard	
				Caution Zone	Hazard Zone
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: E-waste in India - a short documentary by Green Peace [30]					

Table-6. Occupational hazard -CPU (Formal unit).

Dismantling steps for Reuse/Recycling	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
Source: video taken in Techlogic dismantling unit, Bangalore					

Table-7. Occupational hazard -hard disk (Formal unit).

Dismantling steps for Reuse/Recycling	Tools used	Time taken for 25 units	Body movement while doing the task	Ergonomic hazard	
				Caution Zone	Hazard Zone
Removal of screws, actuator, platter and metal plate	screw drivers (flat, T8 star bits), circlip plier, tweezers	3 hrs 47 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
		57 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	Nil	Nil
Source: video taken in Techlogic dismantling unit, Bangalore					

From the results obtained, it can be noted that it takes more disassembly effort to dismantle a CRT monitor (DEI 395), followed by Hard disk (DEI 228), Mobile phone PWB (DEI 64), PCB dismantled by heating and hammering (DEI 57) and PCB dismantled by chiselling (DEI 48). The number of disassembly steps it took to dismantle CRT monitor, Hard disk, Mobile phone PWB and PCB were 11, 7, 3 and, 1 respectively. Thus it can be observed that the more the number of disassembly steps, the higher is the Total DEI score. But interestingly, it was identified that the most difficult disassembly step out of all the disassembly processes carried out is the removal of transistors and capacitors from PCB, irrespective of whether it is dismantled in the formal sector or in the informal sector. Followed by this step, the next most difficult disassembly steps are shown in Table-8. Once the most difficult steps are identified, the factors contributing to a high DEI score could be identified. These factors could then be addressed in the design stage, in order to improve the disassemblability of products, thereby reducing the disassembly effort when the products reach their EoL phase.

From the ergonomic risks results, it was observed that the risks associated with the informal sector are far more serious than those in the formal sector, and requires immediate action. All ergonomic risks undergone by the dismantlers in informal sectors such as awkward postures, high hand force and high repetitive motion falls in the Hazard Zone. In the formal sector, one risk (high hand force) falls in the Caution Zone, confirming the existence of moderate risk, one risk (awkward postures) in the Hazard Zone; other than this, there are no other serious ergonomic risks involved in the formal sector. Also, highly repetitive motions, like hammering by a steel rod and hammering by a hammer, confirms the necessity for immediate action on dismantling activities carried out in informal sectors.

Table-8. Most difficult disassembly steps based on total DEI score.

Dismantled Unit	Sector	Difficult disassembly steps	Disassembly tools used	Total DEI score
PCB	Informal	Removal of transistors and capacitors from PCB by using chisel and hammer along with a brick support	Chisel and hammer	57
PCB	Informal	Removal of transistors and capacitors from PCB by heating and then hammering by a steel rod	Steel rod	48
CRT monitor	Formal	Removal of wires from PCB	Pliers	45
CRT monitor	Formal	Chiselling out the capacitors from PCB	Chisel	45
CRT monitor	Formal	Removal of whole plastic casing by unscrewing 6 screws	Screwdriver	38
CRT monitor	Formal	Removal of front plastic casing by unscrewing 4 screws	Screwdriver and pliers	37
CRT monitor	Formal	Cut the connection wires inside the monitor using pliers	Pliers	37
CRT monitor	Formal	Removal of side cover by chiselling out	Chisel	37
Hard disk	Formal	Remove the outer lid by chiselling out	Chisel	37
Hard disk	Formal	Removal of 4 hidden screws beneath the label	Screwdriver and chisel	37
Hard disk	Formal	Removal of 6 screws from the spindle outer cover and removal of outer cover	Screwdriver	36
Mobile phone PWB	Trained individual	Removal of parts and connection pins from PWB	Pliers	36
CRT monitor	Formal	Cut the main connection wires	Pliers	36

CONCLUSIONS

State of art recycling processes in both informal and formal sectors, including dismantling tools used and dismantling issues encountered in these two sectors, have been discussed. Evaluation of DEI and ergonomic hazards has been carried out on various products using existing methods (DEI model and MSD Risk Assessment Checklists). DEI scores calculated for these products have been used in assessing required disassembly effort for dismantling these products. DEI score calculated for each dismantling step has been used in determining the most difficult disassembly steps.

Comparison of results obtained on ergonomic risks associated with the two sectors shows that there are more serious ergonomic risks associated with the informal sector, thus necessitating immediate action on the way dismantling activities are carried out in the informal sector. This confirms that 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.

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