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Insights from Assessing Computer Mice

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Enhancing ease-of-disassembly tools for electronic products: insights from assessing computer mice

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***Abstract*—To make electronic products fit for circular economy strategies such as life extension, refurbishment, and recycling, ease of disassembly is a key design quality. Several tools are available to assess the ease of disassembly of products during the design process, such as the ease of Disassembly Metric (eDiM) and Hotspot Mapping (HSM).**

The eDiM method uses the time-to-dismantle as a unit for calculating the ease of disassembly. The longer it takes to reach a priority part, the lower the ease of disassembly. Hotspot mapping scores the different parts in the product architecture and ranks them on its failure rate (priority parts), activity, time-to-disassemble, embodied environmental impact, and embodied economical value. These tools help designers prioritize which parts of the product need to be redesigned to improve its circularity.

The eDiM tool is quick and easy to use but is based on generic proxy times, which may not be applicable to specific fastener designs or product types. On the other hand, the hotspot mapping tool uses actual recorded times to accurately identify disassembly hotspots. Recording the time-to-disassemble is more accurate, but is also more time consuming and depends on the operator's experience. Therefore it is difficult to come up with reproducible numbers. It is crucial to find the right balance for these tools, to be able to accurately identify hotspots while maintaining the usability.

In this paper, we research how to develop product-specific proxy times in order to reduce the effort required for assessing hotspots. To reach our goal, we conducted a series of experiments to measure the actual disassembly times of different computer mice, and compared them with the predictions from eDiM. The results indicate that the tools provide accurate results for the most dominant fastener type used in this type of product (Phillips screws) but largely deviate from actual results for some other common fastening techniques, such as adhesives. Consequently, generic proxy times could not be used to correctly identify the product design hotspots. The authors suggest specific modifications to the ease-of-disassembly tools to improve their applicability, thereby supporting the design of circular electronics.

***Index Terms*—Ease of disassembly, repairability, circularity**

I. INTRODUCTION

Ease of disassembly refers to the level of difficulty involved in dismantling a product into its individual parts. This metric is crucial for circular strategies such as repair, refurbishment, and recycling. A product with good ease of disassembly allows for easy replacement of broken parts, for extending the product's lifespan, and facilitates the separation of different materials, thus improving recyclability. Overall, ease of disassembly serves as an important indicator of a product's circularity, particularly in the realm of electronics.

One prominent metric used to quantify ease of disassembly is "disassembly time" [1], [2]. Unlike simply counting the number of disassembly steps, disassembly time offers a more realistic reflection of the difficulty of the disassembly process. Several key circularity assessment tools, such as ifixit repairability [3], [4], HotSpot Mapping [5], and ease of Disassembly Metric [6], [7], utilize disassembly time as a key indicator. In a circular supply chain, disassembly time is also useful for assessing labor-intensive tasks, such as in recycling operations or repair services, as it can be used to estimate disassembly costs [8].

Disassembly time can be obtained directly through the time measurement of disassembly activities [9]–[11]. While this approach yields the most realistic disassembly time, it can be time-consuming, and may introduce a high level of uncertainty if well-defined measuring procedures are not in place.

Another approach to determine disassembly time is through predetermined motion-time systems [6], [8], [9], [12]–[14], with the ease of Disassembly Metric (eDiM) [6] being one of the most prominent tools of using such a system. These systems provide unit time databases associated with individual disassembly motions, such as disconnecting a fastener or removing a part. By linking product disassembly information to these databases, the final disassembly time, also known as "proxy time" [4], [5], can be calculated. This disassembly information allows users to predict the final disassembly time

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[8] without physically carrying out the disassembly process, making it a time-efficient tool. However, the accuracy and reliability of proxy time may be a concern [5].

In this paper, we test the reliability of using generic eDiM proxy times for determining redesign opportunities, as compared to actual disassembly times. We conducted an in-depth analysis of the two approaches, using five different models of computer mice as case studies (see Figure 1). Additionally, to qualitatively identify disassembly hotspots, we analyzed both the measured times and proxy times using the HotSpot Mapping Tool (HSM) [5].

Fig. 1. Computer mice 1 to 5.

This paper is organized as follows. Section II introduces the methods of eDiM and disassembly time measurement. Section III presents the results of measured time and eDiM proxy time, and demonstrates how to improve the prediction of proxy time. Section IV introduces how HSM identifies disassembly hotspots, applies the results of disassembly time to HSM, and discusses how improved proxy times can enhance the usability of HSM. In Section V, we summarize this study and provide recommendations for the use of eDiM and HSM.

II. Method

In this section, we introduce the two methods we used to determine the disassembly times of the five computer mice: (A) ease of Disassembly Metric, (B) disassembly time measurement.

A. Ease of Disassembly Metric (eDiM)

eDiM is a predetermined motion-time system developed by the EU Joint Research Center [6], [7]. It can break down any disassembly activities into six basic disassembly tasks:

1) Positioning: positioning/aligning the tool relative to the fastener.
2) Disconnection: disconnecting a fastener.
3) Tool change: picking up and/or putting back a tool.
4) Removing: removing a component.
5) Identifying connectors (fasteners): identifying the location of fasteners.
6) Manipulation of the product: manipulating/flipping the product to access a fastener.

Each of six disassembly tasks is linked to a time database. Users only need to input the relevant information for a disassembly step, which will be connected to the time databases to calculate the overall disassembly time of the step, i.e. the eDiM score.

In this study, we focus on the first two disassembly tasks, as these tasks are determined by the type of fasteners and typically dominate the total disassembly time.

B. Disassembly time measurement

To determine the actual time needed to disassemble the computer mice, we measured the disassembly time of each mouse using two testers who repeated each disassembly step three times, resulting in a total of six measurements per step. Additionally, to ensure consistent measurement of the disassembly time, we applied the following measurement procedure and guidelines.

1. Preparation before measurement. The tester must be familiar with the disassembly of sample products to avoid unnecessary pauses or interruptions during disassembly. The tester should also prepare all tools, including a stopwatch, within reach.

2. In the formal measurement, the tester should disassemble the sample product at a steady, normal pace [6] and record the time for each disassembly step using a stopwatch. Each disassembly step primarily involves removing one type of fastener, starting from the time of picking up a tool to the time of removing a component. If a step does not involve picking up a tool or removing a component, then only the fastener removal time is measured.

3. During the measurement, the tester should exclude time for interruptions or pauses. If there is a pause (due to encountering a difficulty or getting stuck), then the tester should re-measure the step or pause the stopwatch. If there is an unavoidable pause, or if additional time is needed to adjust hand movement, the step should be marked as "non-repeatable". All other steps should be labeled as "repeatable".

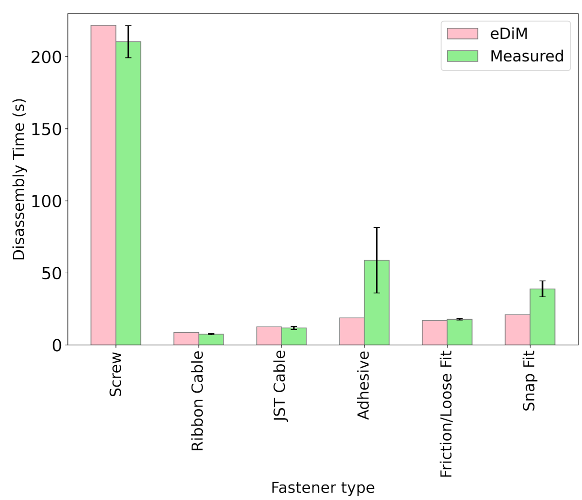

Fig. 2. Measured times vs. proxy times for Mouse 1. Note that the error bars represent the standard deviations of six repeated measurements.

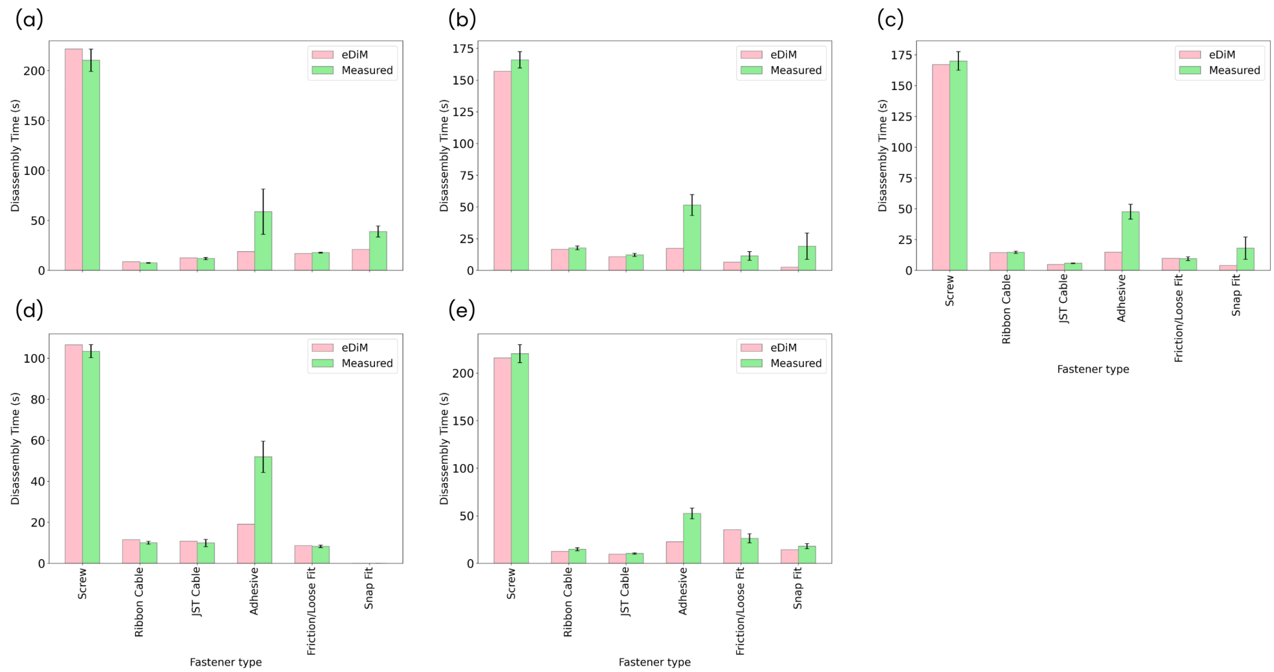

Fig. 3. Measured times vs. proxy times for all mice. Panels (a)-(e) correspond to mice 1-5, respectively.

III. eDiM and Time Measurement

A. Comparison of measured time and proxy time Results

The calculated and measured disassembly times for Mouse 1 are presented in Figure 2 and Table I, categorized according to fastener type. The results show that the disassembly of this mouse is mainly attributed to disconnecting screws and adhesives.

Second, when comparing the eDiM proxy times with the measured times, two main observations are that:

- For screws and cable connectors (ribbon and JST cables), the proxy times are comparable to the measured times. Especially for the dominating screw type, the difference is approximately 5 percent and is comparable to the measurement error itself. This indicates good prediction accuracy of the proxy time on screws.
- On the other hand, for the adhesive type, we found a significant difference between the proxy and measured times, $\sim 70\%$ (see relative error in Table I). This difference is partially linked to the large relative uncertainty in the measured time ($\sim 40\%$), which will be discussed in Section III-B. Similarly, for the snap fit type, there is also a large discrepancy between the proxy and measured times ($\sim 46\%$), with a medium uncertainty in the measurement.

Figure 3 shows similar results for the different computer mice. Firstly, screws consistently accounted for the highest proportion of time (56–65%), followed by adhesives. Additionally, the relative errors and uncertainties in time for screws were consistently small, less than 10%. In contrast, adhesives had the highest uncertainties, and the relative errors were consistently large, greater than 50%. Furthermore, snap fits generally exhibited relatively large uncertainties and errors (some greater than 50%). Finally, for the remaining types of fasteners, cable connectors generally had relatively smaller errors, less than 20%. The errors for friction/loose fits varied, with the relative error on Mouse 2 about 43% and that on Mouse 5 about 34%, while the others were less than 10%. Overall, the proxy-time predictions for screws and cable connectors were consistently accurate, while those for adhesives and snap fits generally had larger errors, with friction/loose fits falling in between.

TABLE I
Measured Time & Proxy Time for Mouse 1.

Fastener Type	Measured Time (s)	Measurement Uncertainty	eDiM (s)	Relative[a] Error
Screw	210.5	5%	221.8	5%
Ribbon Cable	7.5	6%	8.6	16%
JST Cable	11.8	9%	12.6	7%
Adhesive	58.8	39%	18.7	68%
Friction Fit/ Loose Fit	17.8	3%	16.9	5%
Snap Fit	38.9	14%	20.9	46%

[a] The difference between predicted and measured times divided by the measured time.

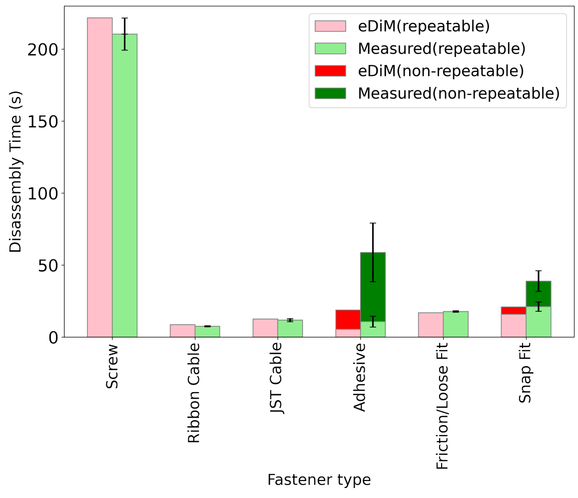

Fig. 4. Measured times vs. proxy times for Mouse 1. In contrast to Figure 2, each bar in this figure illustrates contributions from two distinct types of steps, repeatable and non-repeatable.

B. Analysis of divergent disassembly times

In our analysis, we carefully examined the breakdown of individual disassembly steps to understand the points where the predicted and measured times align and diverge. In Section II-B, we explained how each disassembly step can be categorized as either "repeatable" or "non-repeatable". Repeatable steps involve fixed and easily repeated actions, such as disconnecting screws or simple prying and pulling, resulting in smaller measurement uncertainties. These steps constitute the majority of the disassembly process. In contrast, non-repeatable steps involve more complex fastener designs, such as strong adhesives or complex snap-fits, requiring longer disconnection times and subtle hand adjustments, leading to higher measurement uncertainties. Since these actions are more complex and difficult to be repeated in an identical manner, we labeled them as "non-repeatable".

We marked these complex fasteners/non-repeatable steps in the measurement process and linked them to the results in Figure 3. In Figure 4, the parts represented by the two types of steps are separately highlighted for Mouse 1, showing that non-repeatable steps are associated with discrepancies between eDiM and measured times. In the case of adhesives, they are linked to strong mouse foot adhesives that take a longer time to remove. In the case of snap fits, they correspond to a tight snap fit design associated with the case opening that requires subtle hand adjustments and more forceful prying.

Figure 5 shows the results of the analysis for the five mouse models combined. We noticed that the discrepancies between eDiM and measured times are consistently linked to similar complex fastener designs, particularly strong adhesives for mouse feet and complex snap fits related to case opening. It is evident that these designs are causing the divergent predictions. But on the other hand, because these discrepancies stem from similar design sources, it is possible to make uniform adjustments to their proxy times, as will be discussed in the next section. In addition to the aforementioned types, note that a specific overly tight friction fit in Mouse 2 has also been identified as non-repeatable, requiring subtle hand adjustments and a longer disconnection time.

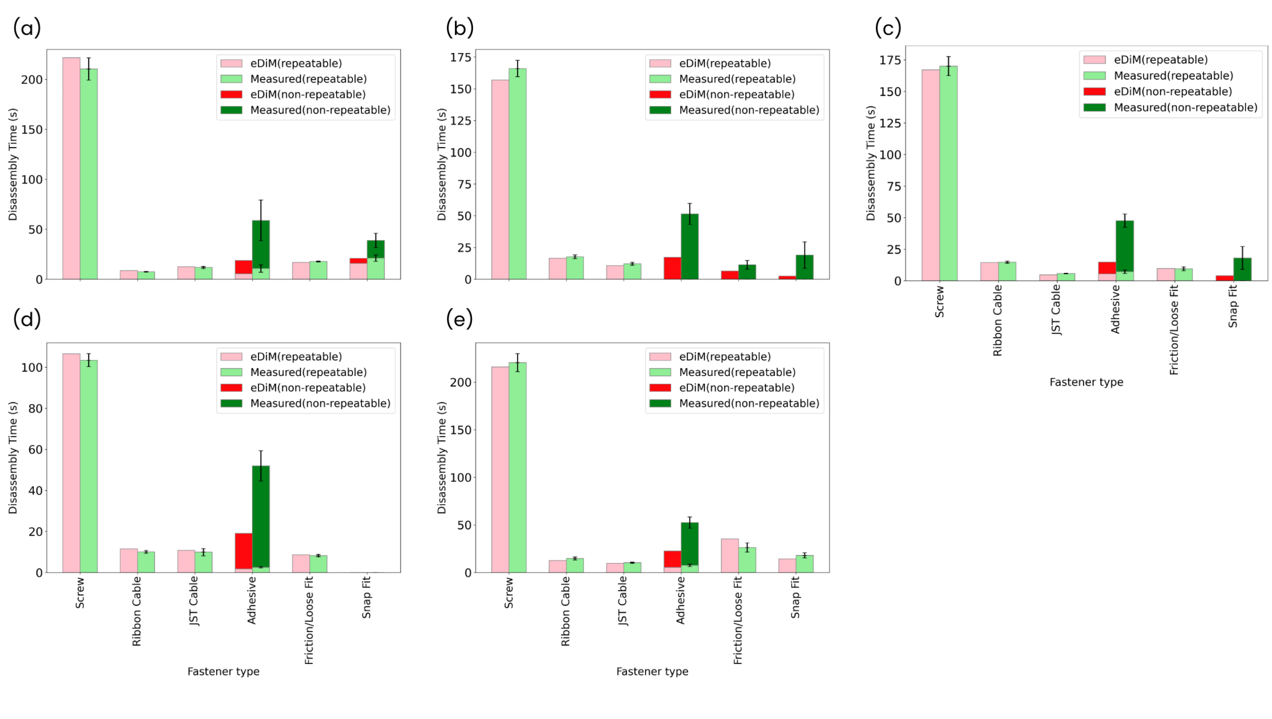

Fig. 5. Measured times vs. proxy times for all mice, with non-repeatable steps highlighted. Panels (a)-(e) correspond to mice 1-5, respectively.

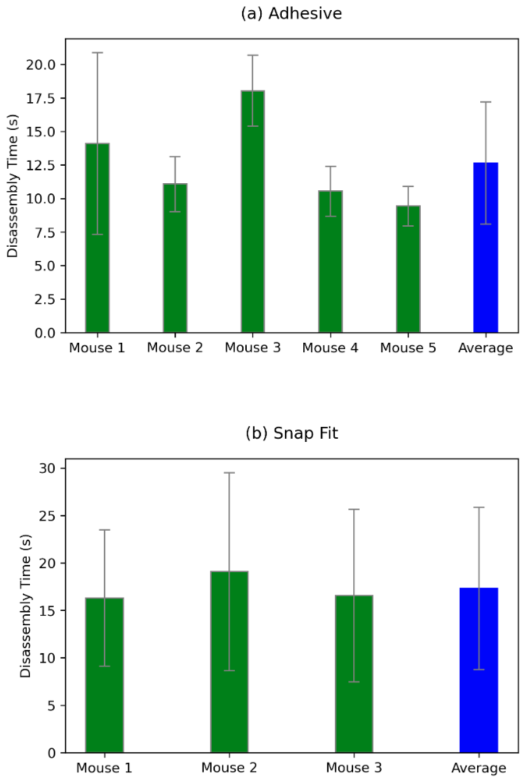

Fig. 6. Measured disassembly times of individual mice and the averages for complex fastener designs: (a) adhesive (b) snap fit.

C. *Modification of proxy times*

In order to better predict disassembly times of computer mice, we adjusted the original proxy times of complex fasteners (labeled as non-repeatable steps) by using the average measured disassembly times. For strong foot adhesives, we calculated the measured time for a single foot adhesive, and then averaged it for all mice. Similarly, for the case-opening snap fits, we calculated the average measured time for mice 1 to 3. Figure 6 shows the measured times of individual mice and the averages. Similar to the approach in [9], which used average measured times as proxy times, we replaced the original inconsistent proxy times with these averages. Figure 7 shows the results calculated using the adjusted proxy times. Although some discrepancy remains, we can see that they are closer to the actual measured times than the original predictions.

We also want to emphasize that for non-repeatable steps, there is a larger uncertainty in the measurements, which can be seen from their error bars in Figure 6. Therefore, we can only make rough estimates using the above modification, and it is difficult to achieve precise predictions. In addition, the averaging of times for different mice should be viewed as a product or design-specific approximation. This is based on the same product category (mouse) and fastener designs in the same areas (mouse feet, case opening). If fastener designs are significantly different or they are used in different product categories, the averaging method may not be able to improve the predictions, as it has not been validated in such scenarios.

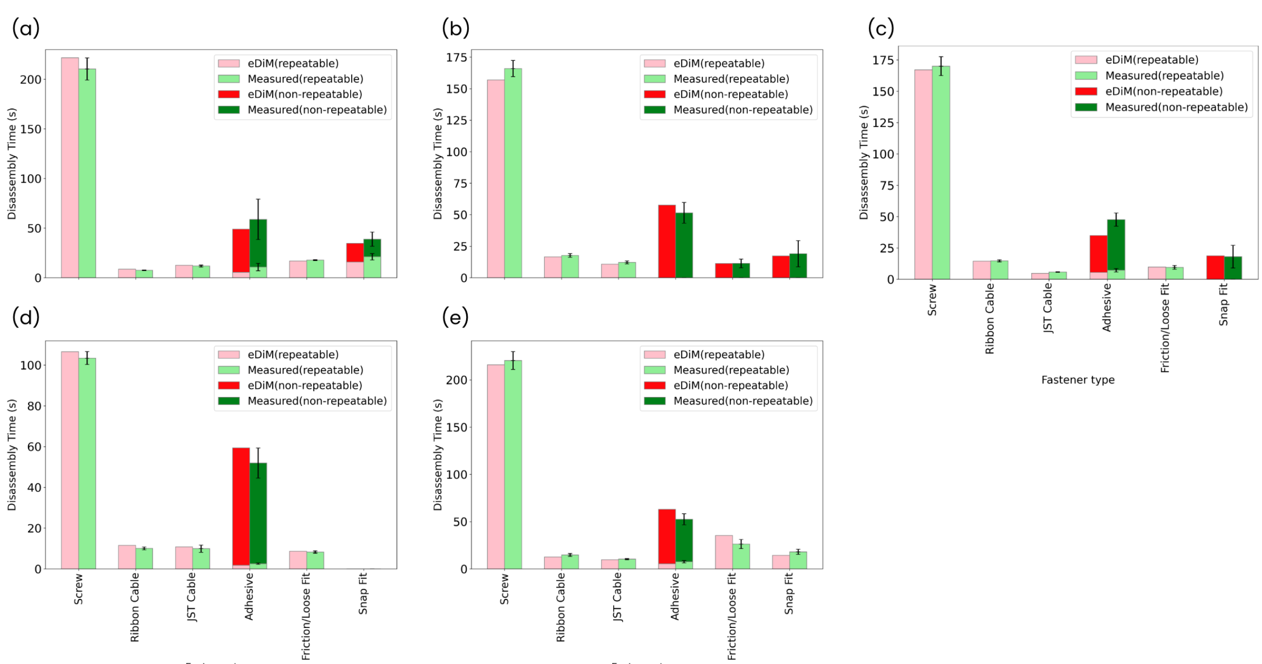

Fig. 7. Measured times vs. modified proxy times for all mice, with non-repeatable steps highlighted. Panels (a)-(e) correspond to mice 1-5, respectively.

IV. HotSpot Mapping (HSM)

For ease-of-disassembly assessment, qualitatively identifying disassembly hotspots, where the most difficult disassembly occurs in the product, is often more relevant than obtaining precise disassembly times. The HSM tool is particularly useful in this regard.

The HSM method typically relies on measured disassembly time, but in principle, it can also use proxy times to identify disassembly hotspots [5], thus reducing the time and effort required for measurement. The only issue to clarify is whether proxy times can accurately point out the same hotspots.

In this section, we explain the time flagging system in HSM, compare the results of HSM using measured times versus eDiM proxy times, and explore the potential for enhancing HSM through the integration of eDiM.

A. Flagging disassembly hotspots with HSM

The HSM tool can be utilized to assess hotspots in five different aspects [5]: time, activity, priority part, environmental, and economic. For the purpose of this paper, we concentrate solely on the "time" hotspots, which represent the most time-consuming steps in the entire disassembly process.

The identification of time hotspots depends on the percentile of a disassembly step in relation to its disassembly time. If the step falls above the 90th percentile, the HSM tool marks it with a red flag; if it falls between the 80th and 90th percentiles, it is marked with a yellow flag.

B. HotSpot Mapping results

We filled out the HotSpot Mapping tool for each of the computer mice using the outcomes of the above tests in the tool column "total time to disconnect": (a) using the average measured times, (b) using the original eDiM times, (c) using the modified eDiM times.

We applied the three sets of time data to the HSM, and Figure 8 shows the results for Mouse 1. Here, we used actual measured times as the reference to compare the predictions of the original proxy times and the modified ones. For the most dominant hotspot, the foot adhesive (step number 1), we can see that the modified proxy times successfully indicate it into "the hotspot (red flag)" while the original one fails to (no flag). This is a major improvement in hotspot prediction. The modified proxy times correctly predict all primary hotspots (red flags). The sole inconsistency arises at a secondary hotspot (yellow flag), where the disassembly time is close to another step with a proxy time error of approximately 20%, affecting the final sequence of hotspots.

Additionally, we conducted the same HSM analysis for all the mice, and obtained similar results as shown in Figures 9-12. The modified proxy times clearly improved the prediction of hotspots, especially for the foot adhesives (only one misidentified as a secondary hotspot), and most of the other hotspots were identified. For all mice combined, the number of inconsistent steps is reduced from 12 to 4 (regardless of flag colors).

Step number	Fastener Type	Fastener Quantity	Time to disconnect - Measured	Time to disconnect - eDiM	Time to disconnect - eDiM Modified	Time - Measured	eDiM - Original	eDiM - Modified
1	Adhesive	3	48.1	13.3	43.6	red flag		red flag
2	Screw	4	27.9	24.5	24.5	yellow flag	yellow flag	
3	Snap Fit	1	17.8	5.0	18.7			
4	Ribbon Cable	2	7.5	8.6	8.6			
5	JST Cable	1	5.0	6.1	6.1			
6	Adhesive	1	10.7	5.4	5.4			
7	Screw	2	14.4	13.0	13.0			
8	Snap Fit	1	3.2	3.2	3.2			
9	Screw	1	5.3	7.2	7.2			
10	Friction/Loose Fit	1	3.1	3.2	3.2			
11	Screw	4	21.4	24.5	24.5		yellow flag	
12	Snap Fit	2	13.6	9.4	9.4			
13	Screw	7	37.9	41.8	41.8	red flag	red flag	red flag
14	Snap Fit	1	4.4	3.2	3.2			
15	Screw	4	24.4	25.9	25.9	yellow flag	yellow flag	yellow flag
16	Screw	2	10.3	11.5	11.5			
17	Friction/Loose Fit	1	2.7	3.2	3.2			
18	Friction/Loose Fit	1	3.1	4.0	4.0			
19	Friction/Loose Fit	1	5.9	3.2	3.2			
20	Friction/Loose Fit	1	3.0	3.2	3.2			
21	Screw	2	14.5	14.4	14.4			
22	Screw	5	31.2	30.2	30.2	red flag	red flag	red flag
23	Screw	5	23.2	28.8	28.8		red flag	yellow flag
24	JST Cable	1	6.8	6.5	6.5			

Fig. 8. HotSpot Mapping for Mouse 1.

C. Possibility of integrating eDiM into HSM

In the previous section, we directly inserted eDiM proxy times into the "time to disconnect" column of HSM, but we see an opportunity for further integration of the eDiM tool within the HSM, enabling a more direct evaluation of time hotspots.

Both tools use a list of disassembled parts and tools, which could easily be combined into one tool. One subtle aspect that could also be integrated is the information on disconnection: eDiM uses "fastener types and quantity" for the disconnection task [6], while HSM uses "activity" (type of disconnection action) [5].

This integration would not only speed up the analysis but also allow for the evaluation of hypothetical disassembly scenarios during the design phase.

V. Conclusion

In this study, we utilized ease-of-disassembly tools to assess five computer mice, focusing on the disassembly time associated with their fastener designs. Our analysis compared the eDiM proxy times with actual measured times, confirming its validity for certain fastener types. For fasteners with fixed and standard designs like screws, cable connectors, or other easily pried or pulled open fasteners, the existing proxy-time tool provided quick and accurate predictions, independent of product categories.

Conversely, for some special and complex fastener designs in the mice, such as strong foot adhesives, the disassembly time could not be accurately predicted. To address this, we used the average measured times as new proxy times to enhance our predictions. While the modified time data we suggest for mice may not be directly transferable to other product categories or fastener designs, the same measurement and averaging methods can be applied to improve the proxy-time tool, making it adaptable to varying product types or fastener designs.

Finally, we applied the proxy time results to HSM, significantly accelerating the assessment of disassembly hotspots compared to using measured times. The use of modified proxy times improved the prediction of hotspots, enabling the identification of critical hotspots previously overlooked with the original proxy times. Further integration of the HSM and the proxy-time tool seems worthwhile in providing designers a quick assessment of the ease of disassembly, offering sufficient accuracy for identifying redesign priorities and comparing design alternatives.

Step number	Fastener Type	Fastener Quantity	Time to disconnect - Measured	Time to disconnect - eDiM	Time to disconnect - eDiM Modified	Time - Measured	eDiM - Original	eDiM - Modified
1	Adhesive	4	51.5	17.3	57.6	🚩		🚩
2	Screw	5	32.8	30.2	30.2	🚩	🚩	⚑
3	Screw	1	8.0	7.2	7.2			
4	Snap Fit	1	19.1	2.5	17.3			
5	Ribbon Cable	1	6.7	6.5	6.5			
6	Screw	5	31.7	31.7	31.7	⚑	🚩	🚩
7	Screw	2	13.9	11.5	11.5			
8	Ribbon Cable	1	6.3	5.0	5.0			
9	Friction/Loose Fit	1	11.3	6.5	11.3			
10	Screw	3	21.7	20.2	20.2		⚑	
11	Screw	2	10.4	11.5	11.5			
12	JST Cable	1	5.8	6.1	6.1			
13	Ribbon Cable	1	4.7	5.0	5.0			
14	JST Cable	1	6.4	4.7	4.7			
15	Screw	2	16.6	14.4	14.4			
16	Screw	5	31.0	30.2	30.2	⚑	🚩	⚑

Fig. 9. HotSpot Mapping for Mouse 2.

Step number	Fastener Type	Fastener Quantity	Time to disconnect - Measured	Time to disconnect - eDiM	Time to disconnect - eDiM Modified	Time - Measured	eDiM - Original	eDiM - Modified
1	Adhesive	2	40.4	9.4	29.5	🚩		⚑
2	Screw	5	34.9	30.2	30.2	🚩	🚩	🚩
3	Ribbon Cable	1	5.2	6.5	6.5			
4	JST Cable	1	5.7	4.7	4.7			
5	Adhesive	1	7.2	5.4	5.4			
6	Screw	5	27.6	31.7	31.7	⚑	🚩	🚩
7	Screw	5	31.5	28.8	28.8	⚑	⚑	⚑
8	Snap Fit	2	18.0	4.0	18.7			
9	Screw	4	23.5	24.5	24.5			
10	Friction/Loose Fit	2	6.2	6.5	6.5			
11	Screw	4	25.6	25.9	25.9		⚑	
12	Ribbon Cable	1	5.2	5.0	5.0			
13	Ribbon Cable	1	4.3	2.9	2.9			
14	Screw	3	20.3	20.2	20.2			
15	Screw	1	6.5	5.8	5.8			
16	Friction/Loose Fit	1	3.3	3.2	3.2			

Fig. 10. HotSpot Mapping for Mouse 3.

Step number	Fastener Type	Fastener Quantity	Time to disconnect - Measured	Time to disconnect - eDiM	Time to disconnect - eDiM Modified	Time - Measured	eDiM - Original	eDiM - Modified
1	Adhesive	4	49.4	17.3	57.6	🚩		🚩
2	Screw	4	25.6	24.5	24.5	⚑	🚩	⚑
3	Ribbon Cable	1	5.0	6.5	6.5			
4	Adhesive	1	2.5	1.8	1.8			
5	Screw	5	29.4	30.2	30.2	🚩	🚩	🚩
6	Friction/Loose Fit	1	5.0	5.4	5.4			
7	Screw	3	15.1	18.7	18.7		⚑	
8	Friction/Loose Fit	1	3.3	3.2	3.2			
9	JST Cable	1	4.7	6.1	6.1			
10	Ribbon Cable	1	5.1	5.0	5.0			
11	JST Cable	1	5.2	4.7	4.7			
12	Screw	2	15.1	14.4	14.4			
13	Screw	3	18.3	18.7	18.7		⚑	

Fig. 11. HotSpot Mapping for Mouse 4.

Step number	Fastener Type	Fastener Quantity	Time to disconnect - Measured	Time to disconnect - eDiM	Time to disconnect - eDiM Modified	Time - Measured	eDiM - Original	eDiM - Modified
1	Adhesive	4	44.9	17.3	57.6	🚩		🚩
2	Screw	7	42.3	41.8	41.8	⚑	🚩	⚑
3	Ribbon Cable	1	5.0	5.0	5.0			
4	JST Cable	1	5.9	6.1	6.1			
5	JST Cable	1	4.5	3.6	3.6			
6	Screw	3	19.3	20.2	20.2			
7	Screw	1	6.2	5.8	5.8			
8	Adhesive	1	7.5	5.4	5.4			
9	Screw	4	25.8	24.5	24.5	⚑	⚑	
10	Friction/Loose Fit	4	9.3	13.0	13.0			
11	Screw	2	15.4	14.4	14.4			
12	Screw	4	24.3	23.0	23.0			
13	Ribbon Cable	1	9.8	7.6	7.6			
14	Friction/Loose Fit	4	12.0	15.8	15.8			
15	Screw	10	62.0	59.0	59.0	🚩	🚩	🚩
16	Friction/Loose Fit	2	5.0	6.5	6.5			
17	Screw	4	25.1	27.4	27.4		⚑	⚑
18	Snap Fit	4	18.0	14.4	14.4			

Fig. 12. HotSpot Mapping for Mouse 5.

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