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# TOWARDS SUSTAINABLE ELECTRONICS: OPTIMIZING AUTOMATED SMARTPHONE DISASSEMBLY PERFORMANCE VIA SIMULATION METAMODELING

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## ABSTRACT

Addressing the urgent challenge of electronic waste, this research investigates an optimization framework for automated smartphone recycling lines. We combine discrete event simulation with response surface metamodeling to analyze and improve the throughput of high-speed disassembly. This simulation model portrays the real disassembly procedure, from pre-processing (sorting and adhesive disabling) through AI-assisted X-ray structural analysis, precision weakness creation via press-cutting, to final component separation by impact. Experimental design explores six operational parameters, revealing that sorting and freezing speeds—particularly their synergistic interaction—exert dominant influence on the system output. The derived quadratic metamodel enables rapid, resource-efficient performance prediction without repeated simulation, which eventually leads to the identification of optimal configurations for maximum efficiency.

## 1 INTRODUCTION

Smartphones characterize contemporary innovation, but their transient average lifespan of 2.5 years contributes to a detrimental legacy of electronic waste (e-waste). Forecasts suggest that the global e-waste will escalate to 74.7 million metric tonnes by 2030, releasing toxic substances and wasting over $57 billion annually in recoverable metals (Forti et al. 2020). The crisis is intensified by design intricacies: attached batteries, exclusive screws, and rapid model transitions translate into "recycling-unready" devices (Gupta et al. 2021). As a result, manual disassembly is economically unfeasible, limiting material recovery to less than 20% for essential elements such as cobalt and indium (Forti et al. 2020; Gupta et al. 2021). The circular economy relies on redefining disassembly as a precise, rapid industrial process, necessitating that disassembly coincides with the efficiency of assembly lines.

Next-generation disassembly leverages cryogenic freezing, deep learning-enhanced X-ray imaging, and robotic impact separation and can reportedly achieve an over 88% disassembly success rate for a speed of up to 600 units/hour (Ueda et al. 2024). Nevertheless, going beyond physical prototyping and employing computer simulation is necessary for optimizing such complex systems. We address this gap by integrating discrete event simulation (DES) with metamodeling via response surface method (RSM). Here, DES emphasizes process interdependencies by developing a dynamic digital twin that encompasses stochastic real-world variables (Attar et al. 2023), whereas the RSM-based metamodel synthesizes several simulated interactions into a predictive mathematical function (Attar et al. 2025). This synergy facilitates ultra-rapid throughput forecasting, substituting time-consuming simulation runs with millisecond metamodel queries—a transformative advancement for fast line calibrations (Amaral et al. 2022).

## 2 METHODOLOGY

The applied methodology comprises two main phases: DES modeling and RSM-based metamodeling. A DES model is developed in Tecnomatix Plant Simulation to replicate a high-speed automated smartphone disassembly line, parameterizing its six key stages (Figure 1): receipt sorting, cryogenic freezing, AI-guided X-ray scanning to identify the location of components, press-cutting for screws, impact disassembly, and

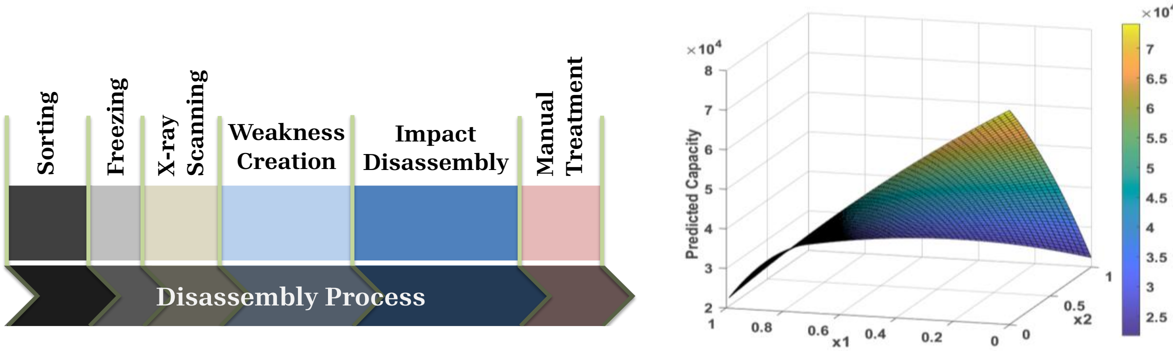


Figure 1: Simplified process sequence of the proposed automated disassembly (left), and the interaction between the Sorting and Freezing coefficients ($x_1$ and $x_2$, respectively) if $x_6$ is fixed to 0.5 (right).

manual rework (for incomplete cases). Our model incorporated real-world stochasticity and industry-reported timings. Separate drains are also used to track automatically disassembled units versus those requiring manual intervention, enabling granular analysis of operator dependencies. The model's scalability was ensured by defining factors $x_{1-6}$ as multipliers of the mean process times of these six stages, translating physical line adjustments into parameters for subsequent experimental design. We utilized RSM to generate 59 experiments for these parameters. The simulation model then predicted the response capacity under each scenario. Eventually, a mathematical quadratic formula (Figure 1) is fitted to the collected data that can be leveraged to predict the system's overall performance within a wide range of parameter values.

## 3 CONCLUDING REMARKS

The statistical results of the regression process (with $R^2 = 0.95$) revealed that the nominal capacity of such systems only has a significant correlation with three of the six parameters: sorting, freezing, and manual treatment. Among these, the first two exert the strongest influence on the throughput of this line, with their synergistic interaction ($x_1 x_2$) partially counteracting individual negative linear effects. The quadratic regression metamodel identified a concave performance landscape where maximum throughput (~80,000 units monthly) occurs at minimal $x_1$ and $x_2$, and it sharply declines as they increase, indicating the significant dependence of the process on these two among all factors. Manual treatment ($x_6$) has also emerged as a critical factor, modulating the effect of these two through its interaction terms (i.e., $x_1 x_6$ and $x_2 x_6$). This non-intuitive interplay suggests that blindly accelerating one stage may not yield better returns if downstream bottlenecks remain unaddressed. This necessitates deeper analysis to provide actionable guidance for actual facility operators. With the achieved flexibility in throughput, the proposed disassembly lines can significantly impact the integration of circularity into the core of the smartphone industry.

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