# Use of Sensors for Cell Phones Recovery

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**Abstract**
In this paper, we analyze the benefits of sensors in cell phone disassembly and remanufacturing. Two different products, conventional cell phones (CCPs) and sensors embedded cell phones (SECPs), are compared to evaluate the benefits of sensors. Discrete event simulation is used to develop the models for each product. Design of experiments are applied by using orthogonal arrays method. Averages and intervals are used to observe the differences between two products. SECPs resulted in higher profit compared to CCPs.

**Keyword:** Product recovery, Sensor embedded products, Remanufacturing

## Introduction

Protecting the environment has been a topic of growing interest in human life and has also found its way into the manufacturing arena during last few decades. The term, Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) was explained and detailed by Gungor and Gupta (1999). After that study, many studies have been conducted in the area of ECMPRO and its subareas. Ilgin and Gupta (2010a) published an updated overview of ECMPRO and its subareas including product design, reverse and closed-loop supply chains, remanufacturing and disassembly. The idea was to include the concept of ECMPRO in manufacturing a product from its design phase to its end of life (EOL) phase. Reverse supply chain is a way of implementing this idea.

Reverse supply chain has become an area of active research recently because of law enforcements and increasing consumer awareness. Many different kinds of products have been produced since the beginning of industrial revolution and once those products complete their useful lives they were typically disposed of. Companies and governments realized that landfilling would not be appropriate for all produced goods and thus the need for solutions surfaced. As a result of that, collecting EOL products, recycling and remanufacturing them have gained significant attention. Reverse supply chains basically consists of these steps. They include high degree of uncertainty since the amount of returns and the quality level of these returns cannot be accurately estimated. Existing literature has offered many solutions to reverse supply chain related problems including inventories, facility and collection center locations, routing problems and estimating the number of returns. One of the solution ideas to deal with uncertainty of EOL product's quality is embedding sensors into products. Ilgin and Gupta (2010b) reported a study where the benefits of sensors were highlighted. Sensors help to track the product's condition, age, the environment that it was used in, etc. Ilgin and Gupta (2010b) investigated the value of sensors and Ondemir and Gupta (2014a,b) explained their effect on product returns.

The purpose of this study is to analyze the importance and value of sensors in SECPs and evaluate the performance of the SECP remanufacturing system. The models for both CCPs and SECPs consist of collection of cell phones, disassembling them and classifying the parts into quality levels to remanufacture them when fulfilling the remanufactured cell phone demand. Discrete event simulation is used to run and compare the models. Factors affecting the sensor performance are defined and design of experiments with orthogonal array approach is applied. The performance measures are revenues and costs, such as collection, disassembly, disposal, remanufacturing, holding and backordering.

## Literature Review

One of the earliest examples of the idea to use sensors in product recovery was launched by Vadde et al. (2008). They suggested that embedding sensors are economically feasible and those sensors should be used to obtain lifetime information from the products. Ilgin and Gupta (2010b) studied the benefits of sensors and compared sensor embedded systems with conventional collection and disassembly systems. EOL washing machines and refrigerators embedded with sensors are disassembled in a multi-product disassembly line when they are returned. The economic contribution of the sensors was significantly higher than their costs.

Ilgin and Gupta (2011a, b, c) adopted similar approach and applied it to different products in order to observe the benefits of sensors. The products were dryer, dish machine, air conditioner and computers. Ondemir et al. (2012) proposed an optimization model consisting of disassembling EOL products and classifying them into different quality bins in terms of condition of products and their remaining lives. The goal of this model was to minimize the cost of disassembly, recycling, repairing and procurement and fulfill the remanufactured product demands. Selecting the proper components from returned products and remanufacturing them was the basic concept of this study.

Ondemir and Gupta (2012) implemented Generic Algorithm to solve the problem for collecting EOL products and remanufacturing them. Fuzzy programming and mathematical programming were proposed by Ondemir and Gupta (2013a, b) for the problem. Linear Physical Programming and Internet of Things approach were suggested to solve disassemble-to-remanufacture problem for product recovery (Ondemir and Gupta 2014a, b).

## System Description

The aim of this study is to observe the benefits of sensors. Thus, two systems were developed which are CCP and SECP systems. When the EOL cell phones are collected they are disassembled using a 5 station disassembly line. It is assumed that a cell phone has 5 components which are back cover, battery, audio set, circuit board and screen and they are disassembled in that order. Figure 1 shows the disassembly line and stations. SECPs go through the stations if the components are not missing and reusable. If a component is not reusable it is not disassembled. Once the disassembly is complete, a decision on the components is made to reuse, recycle or dispose of them after inspection. In SECP system, inspection is not needed since sensors provide this information upfront. If the components can be recycled, scrap generates revenue for the system If they cannot be recycled because of the nature of its raw material they are typically disposed of.

Reusable components are classified into different quality levels based on estimated remaining lives and their conditions. A component that has an estimated lifetime of at least 3 years is a high quality component whereas medium quality component has an estimated lifetime from 1 year to 3 years and low quality one has at least 6 months up to 1 year estimated lifetime. Components are used to be remanufactured based on these quality levels.

The systems do not allow having excess inventory and limit the maximum inventory levels for both components and remanufactured cell phones, because one of the goals of sensor application is to reduce inventory costs. When there is enough inventory of remanufactured cell phones, the components are also sold.

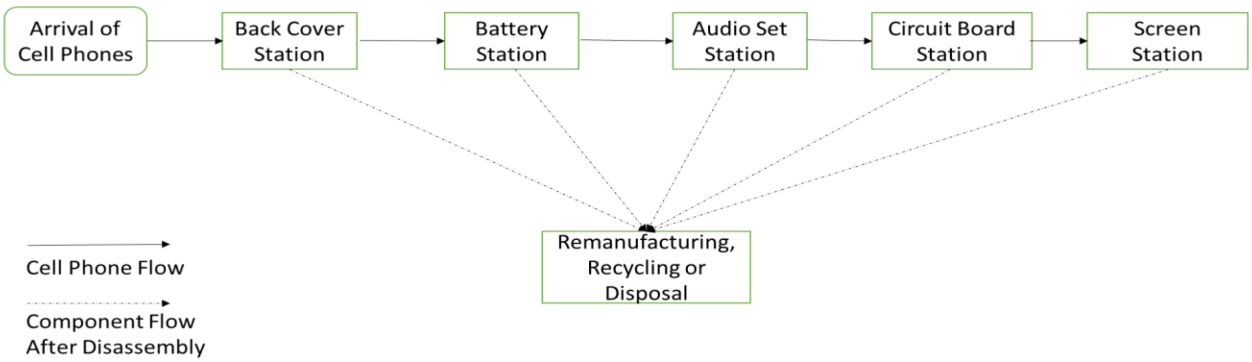


*Figure 1: Flow of EOL Cell Phones and Disassembled Components*

## Design of Experiments Study

The two systems were simulated and compared in order to determine the value of sensors. For experiments, 63 factors were identified, each of them having 2 different levels. Orthogonal Arrays approach was used to conduct experiments. 64 experiments were needed (Phadke 1989). Models were developed by discrete event simulation using Arena 14.7 (Kelton and Sadowski 2007). The models for SECPs and CCPs were run for a year with 5 replications.

The goal of the experiments was to compare the total profit for both systems using different costs such as disassembly, inspection, holding and backordering costs.

$$\text{Total Profit} = \text{Total Revenue} - \text{Total Cost} \quad (1)$$

$$\text{Total Revenue} = RCPSR + CSR + SR \quad (2)$$

$$\text{Total Cost} = DC + CC + DiC + AC + IC + HC + BC \quad (3)$$

RCPSR is the revenue generated by selling remanufactured cell phones and CSR is component sales revenue. There exist demands for each quality level remanufactured cell phones and they are uniformly distributed. Selling price and demands were included as factors. SR is scrap revenue and it is based on weight of recycled components. DC is cost to disassemble the EOL cell phones. CC is collection cost for EOL cell phones. DiC is disposing cost of the component that cannot be recycled. AC is assembly cost. IC is inspection cost. HC and BC are holding and backordering costs respectively. Probabilities were also included as factors since they have a direct relationship with the outcome of the systems. These are having missing components, reusability and quality bin probabilities.

## Results

Design of experiment study results are shown in Table 1. Sensor value is determined by the difference between total profits for SECPs and CCPs and total number of sensors used for the system. Based on the sensor value range, one can say that sensors provide economic superiority to the system. Total profit for SECPs is significantly greater than that for CCPs. All of the costs were reduced due to sensors as they were predicted at the beginning of this study. The amount of reduction can be seen in Table 1 as range and average.

*Table 1: Comparison of Experiments*

| **Comparison** | **Range ($)[SECP-CCP]** | **Average ($)** |
|---|---|---|
| Sensor Value | [-0.24, 5.42] | 1.77 |
| Total Profit | [-668.92, 14839.78] | 4850.18 |
| Disassembly Cost | [-4901.63, -808.60] | -2249.79 |
| Inspection Cost | [-3373.71, -1482.28] | -2291.66 |
| Holding Cost | [-88.48, 78.03] | -2.44 |
| Backordering Cost | [-189.37, 111.59] | -4.41 |

## Conclusions

This study was conducted to show the benefits of sensors in product recovery systems consisting of disassembly and remanufacturing. It has been proven that sensors are useful in product recovery since they provide sufficient information about the conditions of the products and their components. This information is used to eliminate disassembly and inspection costs. In addition, if systems are properly designed, they help in reducing the holding and backordering costs.

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