A method for assessing the obsolescence of electrical appliances considering PCB maintenance

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Abstract

The rise in population and improvement in living standards, particularly in industrialized nations, has resulted in increased use of residential electric appliances and average worldwide energy consumption, as well as increased CO_2 emissions per capita. Washing machines, dishwashers, dryers, mixers, blenders, fridges, power tools, and other domestic electric appliances all include a tiny electric motor within that is electronically controlled. Longer-lasting items, such as residential electric appliances, are a cornerstone method of the circular economy for reducing the usage of non-reusable materials and the amount of trash to be handled at the end of the product's life cycle. Printed circuit boards (PCBs) are used in the production of contemporary electrical appliances. As PCBs get increasingly complex, the risk of failure rises. In this work, we concentrate on PCB's maintenance taking into account the cost of repair and replacement, expressing the most common PCB's failures as a Sequential Quadratic Programming (SQP) problem. The suggested formulation, which was developed in the MATLAB environment, is applied to PCBs related with washing machines.
Keywords: Electrical appliances, energy consumption, failure factors, obsolescence.

1. Introduction

According to energy consumption scenarios, unless substantial changes in policy or technology occur, global consumption would grow by roughly 50% over the next 30 years. Although petroleum and other liquid fuels will continue to be the world's greatest energy source in 2050, renewable energy sources such as solar and wind will expand to a similar level. Falling technological prices and government policies that incentivize renewables will lead to an increase in renewable power output to satisfy rising electricity demand. As a consequence, renewable energy will be the fastest-growing source of energy for all nations. It is expected that coal and nuclear usage in a certain number of nations to be declined, but this will be more than compensated by growing coal and nuclear use in the rest of the nations [1]. A major part of the global energy consumption is related with the corresponding rising of the global overall consumption of electrical and electronic equipment, every year, by million tons. With extraordinary technological innovation and rapid expansion in numerous areas, the amount of public and industrial electrical items per capita has increased significantly over the last 30 years, as have the costs of new products. Simultaneously, the average lifetime of electrical appliances has decreased significantly, resulting in massive electric and electronic manufacturing. According to the United Nations University (UNU), the total global output of waste electrical and electronic equipment (WEEE) in 2014 was 41.8 million metric tons (Mt). Electrical and electronic equipment (EEE) manufacture is a difficult industry for both costly and precious metals, which are used in diverse circuits in small amounts per unit. All developed and developing countries should reclaim valuable metals from these household items as they become outdated [2]. WEEEs are today recognized as one of the world's fastest growing waste streams, with an estimated yearly rate ranging from 3% to 5%, necessitating major waste-management techniques. Reduce, reuse, recycle, and recover are methods of lowering the environmental effect of commerce and manufacturing [3, 4]. Recycling household electrical appliances may allow for a reduction in the usage of natural resources in industry, which may assist to reduce environmental impact [5]. Recycling is widely acknowledged as an important component of the move to ecological sustainability in European Union (EU) waste management initiatives. As a consequence, many legislative frameworks, such as the WEEE guidelines, have been established to define weight-based targets for recovering, reusing, and recycling. Furthermore, the growing significance of raw material procurement has prompted a more comprehensive approach to boost efficiency [6]. In addition, with the amount of garbage produced each year increasing at an alarming pace, electronic waste (E-waste) management has been identified as a key global problem [7]. Under these circumstances, the Circular Economy (CE) idea is proposed as an alternative to yesterday's linear economic model, as well as a plan for achieving sustainable production and consumption. The CE method is a strategy for improving the sustainability of consumption patterns via the optimization of product lifecycles. A recent EU legislative proposal addressed this issue by promoting trash reduction and re-use, as well as significant material recovery. A strategy like this is especially intriguing for the management of WEEE, which is seen as an urban stockpile of diverse metals, particularly precious metals and rare earth elements. The major objective of WEEE management approaches is metal recovery, which has recently gained a lot of attention, especially considering the waste stream's ever-increasing production. However, there is still a lot of room for improvement in order to ensure the overall sustainability of WEEE management [8]. Two of the most cost-effective strategies to preserve resources are reusing and extending the life of equipment. An example of reusability may be defined as an alternative to commodity recycling or disposal in terms of its environmental, economic and social advantages [9]. Nearly 33% fewer raw materials may be used if strong statistical assumptions were made in favor of reuse in the home [10]. There will be a 12 percent decrease in energy use by recycling existing home equipment. Appliances in homes account for around 1.8% of total power usage in the United States, according to the Energy Information Administration (EIA) [11]. On the other hand, limiting the lifetime of appliances for functional and social reasons leads in a huge depletion of resources and a bigger amount of waste [12].

Maintaining a home appliance's printed circuit board is a good way to prolong its life. A Sequential Quadratic Programming (SQP) approach is used to simulate numerous scenarios in MATLAB when a customer's budget is close to the maximum amount of money he or she is prepared to spend. The replacement rate is based on a number of factors, including the amount and cost of PCB components as well as the service costs. It was necessary to utilize the findings of these tests in order to fix washing machine PCBs.

2. Analysis of Printed Circuit Board's components

The proposed methodology is implemented in a washing machine's printed circuit board. Figure I depicts this PCB and its corresponding components. The methodology provided in this paper aims at finding out which of the components presented in Figure I should be changed if a client has a limited budget to work with.

Table I shows the different type of components connected on the PCB, the cost per component in Euros, and the "obsolescence index" of each one of the components.

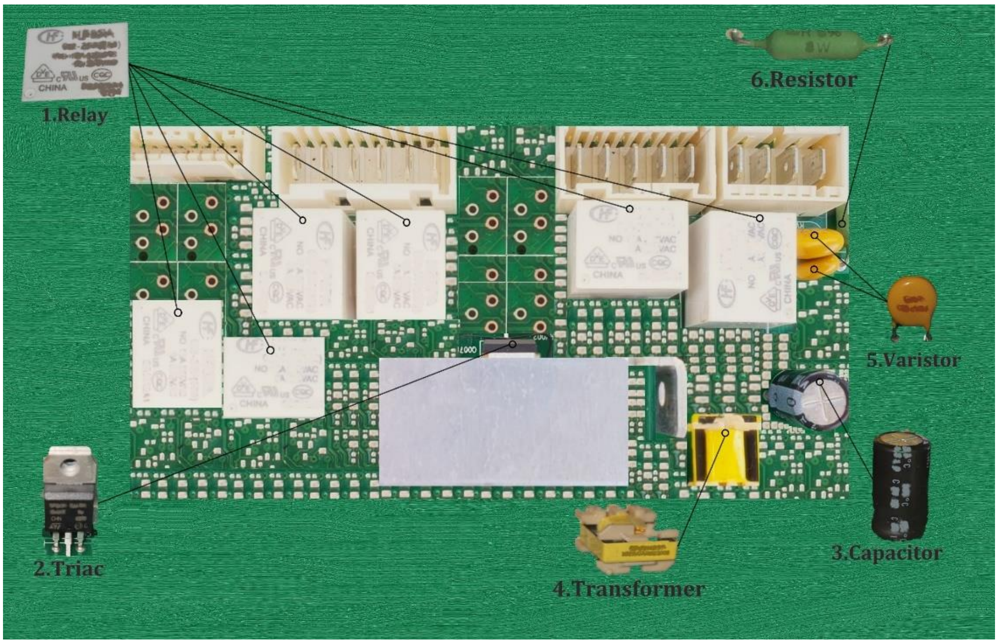

Fig. I. PCB and its corresponding components.

Table I. PCB Components and corresponding cost and obsolescence indices.

PCB Components	Cost (€/Component)	Obsolescence Index O_i
1	2.33	0.85
2	5.64	0.75
3	4.22	0.65
4	4.95	0.80
5	2.36	0.55
6	1.27	0.50

3. Proposed Methodology

Let a PCB that has n different types of components that can be replaced and assume that $x = (x_1, \ldots, x_n)^T$ is the decision variable vector. Given a specific budget by the customer, the problem is formulated as Sequential Quadratic Problem:

$$\text{maximize} \sum O_i \cdot x_i$$
$$s.t. \prod \left(1 - \frac{C_i}{B} \cdot x_i\right) = 0 \qquad (1)$$

where B is the maximum customer's spending capacity, while C_i is the cost in euros (€) for each component. Note that the weight, Oi, expresses the obsolescence index taking values that selected through experimental tests and considering the lifespan of each component.

4. SQP background

Nonlinear programmers consider the Sequential Quadratic Programming approach to be their most powerful problem-solving tool [13]. As with unconstrained optimization, you may nearly emulate Newton's technique using this approach. The Hessian of the Lagrangian function is approximated using a quasi-Newton updating approach at each major iteration. QP subproblems are used to produce a search direction for a line-search technique [13] by solving this subproblem. As stated in the problem description (2), the main concept is to formulate an approximation of the Lagrangian function using a quadratic approximation (3).

$$\max f(x)$$
$$s.t\begin{cases} z_i(x)=0, i=1\ldots m_e \\ z_i(x)\le 0, i=m_e+1\ldots m \end{cases} \tag{2}$$

$$L(x,\lambda)=f(x)+\sum_{i=1}^{m}\lambda_i\cdot z_i(x) \tag{3}$$

After linearizing the nonlinear constraints, the definition of the QP subproblem is:

$$\min_{d\in R^n} \frac{1}{2}\cdot d^T\cdot H_k\cdot d+\nabla f^T(x_k)\cdot d \tag{4}$$

$$s.t\begin{cases} \nabla z_i^T(x_k)\cdot d+z_i(x)=0, i=1\ldots m_e \\ \nabla z_i^T(x_k)\cdot d+z_i(x)\le 0, i=m_e+1\ldots m \end{cases}$$

The QP method may be used to resolve this particular subproblem. In order to create a new iteration, we utilize the solution from the previous one.

$$x_{k+1}=x_k+a_k\cdot d_k \tag{5}$$

By using an adequate line search strategy, α_k is determined considering that a sufficient reduction in a merit function may be achieved. The Lagrangian function's Hessian matrix is approximated by the H_k matrix. The SQP algorithm is implemented in MATLAB environment by using the *fmincon* function and m-files that return the current value of the function and satisfy the corresponding equality constraints related with the obsolescence index and the customer’s budget.

5. Simulation Results

The washing machine PCB described in the previous section and the component specifications of Table II are used to analyze and test the suggested technique. An Intel(R) Core(TM) i7-2600K CPU running at 3.4 GHz and 16 GB of RAM was used to construct the suggested technique in MATLAB. Three distinct scenarios are simulated based on a particular customer's spending capacity.

Table II. Simulated case scenarios.

Scenarios	Customer's spending capacity (€)
A	40.00
B	60.00
C	80.00

Results for simulated cases are shown in Figures II–IV.

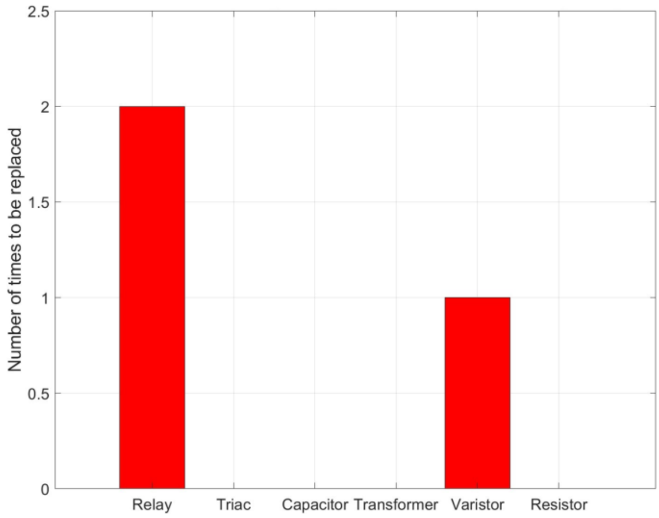

Fig. II. Simulation results for case “A”.

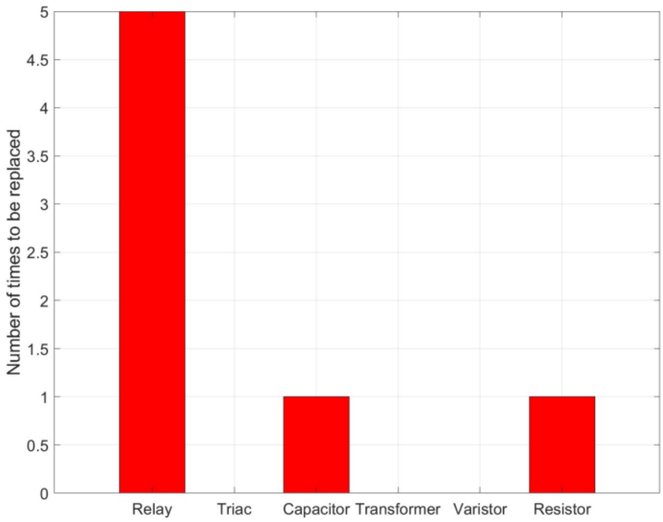

Fig. III. Simulation results for case “B”.

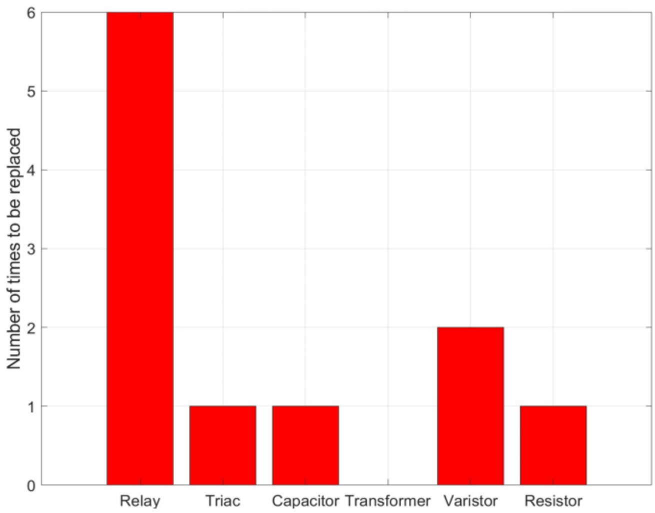

Fig. IV. Simulation results for case “C”.

As a consequence of the above findings, it is clear that as the customer's spending capacity grows, the number of components that may be changed grows as well. Moreover, the most frequently PCB component to be replaced in both three cases is the “relay”.

6. Conclusions

This article investigates a simple, flexible, and straightforward SQP-based strategy for optimizing an objective function associated with the components on a printed circuit board, subject to an equality constraint, while guaranteeing that the overall cost of repair does not exceed a preset amount. The proposed methodology was successfully tested on a PCB associated with a washing machine. From the results, it can be concluded that as the customer's spending capacity grows, the number of renewing PCB components increases, having as a result the extension of the appliance's lifespan.

7. References

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