Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

doi: 10.3850/978-981-18-8071-1_P720-cd

A Bass Diffusion-Inspired Methodology to Predict Device Activity

Ardeshir Raihanian Mashhadi, Ryan Bradely, Lin Shi

Amazon Lab126, USA. Email: ardeshr@amazon.com, ryantb@amazon.com, llinshi@amazon.com

Understanding device activity over the lifetime of consumer electronic products is critical in two ways. First, it determines the extent to which a product maximises utilization during its usage phase, which is a critical pillar of circular products. Second, it allows for better estimations of usage phase carbon footprint, which is essential in Life cycle Assessment (LCA) of consumer electronics. This manuscript proposes a methodology for cold start forecasting of device activity data via a Bass diffusion inspired model to predict Monthly Active Devices (MAD) over the lifetime of a product.

Keywords: Bass diffusion, device activity, circularity, product reliability, optimization, consumer product

1. Introduction

A better understanding of the useful life of consumer electronics has two major benefits. Firstly, optimizing the utilization of a product during its usage phase is a pivotal pillar of a circular product system design, [1] where a key requirement of improving the utilization is extending the life span of products. Secondly, inaccurate estimations of device lifetime can significantly hinder the accuracy of Life Cycle Assessment (LCA) and environmental impacts in consumer electronics [2]. The useful life span of a product is governed by customer engagement, which can be captured via device activity. We can use a device activity metric, such as Monthly Active Devices (MAD) over time, in order to measure the useful life of a device [3]. During the product development cycle when a new generation of a product is launched, an estimation of the useful lifetime of a device is essential for informing the design decisions for the development of the next generation of the device. This manuscript proposes a methodology for cold start forecasting of MAD when only early lifetime device engagement is available.

2. MAD and Device Useful Lifetime

Device useful life can be defines as:

$$L_{avg} = \frac{1}{12}\frac{\sum MAD_i}{Total\ Sales} \quad (1)$$

Where L_{avg} is the average lifetime in years, MAD_i is the number of devices active in a given month over the lifetime of the product.

We have observed that the cumulative MAD profile of most consumer electronics over time follows an S-curve (Figure 1).

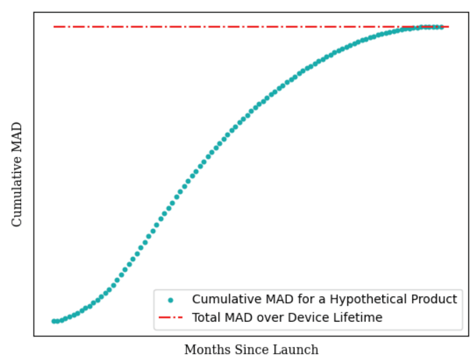

Figure 1 – Cumulative MAD for a hypothetical product

We can use the Bass Diffusion Model, [4] which was developed for technology adoption forecasting, to model the trend of cumulative MAD over time. The Bass model is an S-curve and can be formulated as follows:

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \quad (2)$$

In the original Bass model, $F(t)$ represents the cumulative adoption over time. p is the coefficient of innovation, which represents external influence or advertising effects and q is the coefficient of imitation and represents the internal adoption effects like word of mouth. Since, $F(t)$ is bounded between 0 and 1, we adjust equation (2) with a scaling factor:

$$f(t) = L \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \quad (3)$$

Where $f(t)$ would be the cumulative MAD over time and L would be the total MAD over the lifetime of the device. And p and q are parameters that define the shape of the function.

3. Prediction

The challenge of predicting any S-curve is that early data may not be enough to find a unique solution to the curve-fitting problem needed to construct the whole MAD portfolio across the lifetime of the device. In order to alleviate this problem, we add a penalty function to the objective function to apply the knowledge we have from previous generations to inform the optimization. Using the insights from historic MAD data, we formulate the following optimization problem:

$$\min:[y - (f(t) + E)]^2 \quad (4)$$

Where y is the observed MAD value and $f(t)$ corresponds to the Bass cumulative function and the added penalty term (E) ensures that the values of p^* and q^* stay within the accepted boundaries that make sense relative to the prior knowledge from the previous generations of the same product. We use the Powell's "dog-leg" [5] algorithm to solve the optimization problem formulated in Equation 4. Solving the optimization problem produces the results illustrated in Figure 2. In our case study, this method predicted the total cumulative MAD of a product within 10% of the actual data.

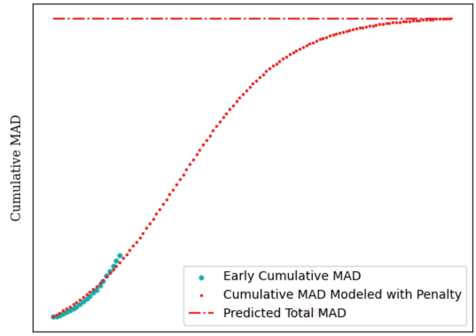

Figure 2 – Prediction of total cumulative MAD using a penalty function

4. Conclusions

Early prediction of device activity over its lifetime is essential in informing the product development cycle to improve the circularity potential of future generations of the product. This study proposes a methodology for cold start forecasting of monthly active devices using the Bass model and a penalized nonlinear optimization approach.

Acknowledgement

We thank our colleagues from Amazon Lab126 for offering their expertise and time for relevant discussion.

References

[1] Circular Electronics Partnership, 2022, "Circular Electronics System Map," https://cep2030.org/files/cep-system-map-2022.pdf.

[2] Teehan, P., and Kandlikar, M., 2012, "Sources of Variation in Life Cycle Assessments of Desktop Computers," J Ind Ecol, **16**(SUPPL.1).

[3] Yiang, K., Bradley, R., and Shi, L., 2022, "A Methodology for Correlating Annualized Replacement Rate (ARR) Reduction to Sustainability Benefits."

[4] Bass, F. M., 1969, "A New Product Growth for Model Consumer Durables," Manage Sci, **15**(5), pp. 215–227.

[5] Powell, M. J. D., 1970, "A Hybrid Method for Nonlinear Equations," Numerical methods for nonlinear algebraic equations, pp. 87–161.