QUANTIFYING TRADEOFFS IN DESIGNING FOR CIRCULARITY

A product life-cycle calculator balances both environmental and financial impacts to inform design decisions.

Remanufacturing, a process that restores end-of-life parts and products so that they can go back into service after they have achieved their useful life. However, for remanufacturing to be successful the product needs be designed for remanufacturing. For this reason, fundamental models and new design tools with capabilities of generating and comparing design for Re-X alternatives considering economic profitability and environmental impact savings need to be developed. These models and tools will enable companies to know more than how much energy will be saved or how much carbon pollution will be avoided with the new design while also understanding how the new Re-X design affects the cost of the component. Many product design tools lack the ability to provide this comprehensive view.

A project based at the University of Illinois at Urbana-Champaign set out to fill this gap in design analysis for Re-X. Researchers developed an assessment tool to quantify the tradeoffs that may arise during the life cycle of product suites designed for Re-X. The tool was applied to test cases including product families of axles and laptops, with help from project partners John Deere and the Green Electronics Council.

PROJECT DESCRIPTION

This two-year project had three main objectives. The first was to embed market-driven product take-back and recovery within a profitability model of Re-X options. Second was to link a part reliability model with Re-X options to plan design and production decisions within a product family. Finally, the project established a trade-off model which optimized the any increase in cost because of Re-X over the lifetime of the component with the environmental impact savings.

Then the team identified the key factors that can be modeled to incorporate Re-X

conditions and decisions into a design for reliability process, integrating interdependence models with existing reliability analysis tools. With multiple objectives identified from the design requirement, the team formulated a multistage optimization model for product family Re-X design.

The resulting Re-X life cycle calculator was applied to two case studies: John Deere axles and laptop products. The tool considers remanufacturing options based on the product's reliability requirements and quantifies the associated cost, energy consumption, and carbon dioxide emissions. By assigning subjective weights in the

tool, the product maker can select the design option that helps achieve desired targets.

PROJECT IMPACT

The developed assessment tool can serve as a building block for product family assessment of Re-X benefits in the initial design phase. Integrating both the environmental and financial benefits of Re-X and avoiding the need to manufacture new materials could achieve at least a 15% reduction in embodied energy and at least a 20% reduction in carbon emissions.

The research team has shared their work through publications and conferences, including presentations at the 2022 Industrial and Systems Engineers Conference, the REMADE 2023 Circular Economy Tech Summit & Conference, and IEEE's 2023 Annual Reliability and Maintainability Symposium.

PROJECT NUMBER: 19-01-DE-01

NEXT STEPS

The current life cycle calculator has been developed within Microsoft Excel. Transitioning the current version to a commercial application with generalized product input will require a few steps, such as expanding the cost, environmental impact data information used; and incorporating detailed remanufacturing process and actions into the assessment process. The project team will use the developed methodology to investigate additional circular economy processes and create improved tools for Re-X design

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PUBLICATIONS

Kim, H. *Quantification of Financial and Environmental Benefits Tradeoff in Multi-Generational Product Family Development Considering Re-X Performances: Final Report for REMADE Project 19-01-DE-01*. October 2023.

Mishra, A. K., Liu, X., Hu, C., and Wang, P. 2023. Reliability-informed End-of-Use Decision Making for Product Sustainability using Two-Stage Stochastic Optimization. Applied Mathematical Modelling, 121, 364-385. https://doi.org/10.1016/j.apm.2023.05.010

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Acknowledgment: "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Advanced Manufacturing Office Award Number DE-EE0007897."