Novel Multi-Dimensional Geometric Metric for Uncertainty in Life-Cycle Assessment

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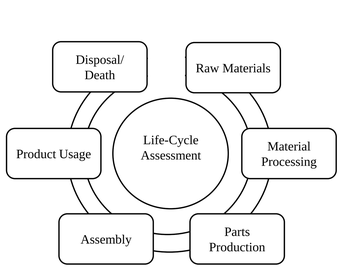
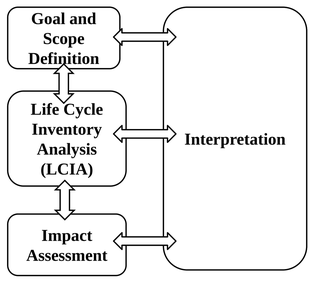
INTRODUCTION

- **Working towards sustainable resource use has become the need of the hour.**
- **Present day manufacturing is making it a necessity to evaluate environmental impact of a product, in its design stage, by utilizing a growing technique called Life Cycle Assessment (LCA).**
- **LCA plays an important role in decision making based on the environmental impacts of processes that take place in a product's life cycle from its birth to cradle stage.**
- **These environmental impacts are measured with relation to global warming effects, eutrophication, acidification, criteria air pollutants, resource depletion, smog, etc.**



Product Life Cycle Diagram



LCA Stages

- **Data used in LCA study is usually assumed to have linear relation between inputs and environmental impacts.**
- **The LCA data has large uncertainty as it is obtained for similar process from different era, technology, geographic location, etc.**
- **The uncertainty in LCA data is for each process in a product's life cycle, including consumables and sub-components.**
- **When computing the environmental impacts of entire product life-cycle, not only the nominal values of the impacts are added, but also the uncertainty in the values of the impacts get accumulated.**

Existing Uncertainty Models in LCA

Authors	*Concepts used*	*assumptions*
Jack W. Baker & Michael D. Lepech	Monte Carlo simulations & approximate analytical methods	Linear input gives Linear output.
Shih-Chi Lo & Hwong-Wen Ma	Bayesian Monte Carlo method	Data estimation techniques, subjective judgment & model's assumption
Morten Birkved, Reinout Heijungs	Meta Model using regression analysis	Model gets scaled based on the input parameter variation
Carlos Ricardo Bojacá, Eddie Schrevens	Monte Carlo simulation to create a Multi-Variate random distribution	Input and output distributions to be multivariate

ABSTRACT

Life-Cycle Assessment (LCA) is a technique used to estimate the environmental impact of any product from its inception to disposal. In mechanical design, LCA is performed at the end of the design stage. This implies that the product is not yet manufactured, used or disposed off. Therefore the data utilized in LCA is estimated from similar products. Data utilized in such LCA study is from different processes, products, technologies, different geographic locations and time frame. Therefore, there is large uncertainty in the data utilized in LCA. The focus of this study is to develop a novel geometric metric to quantify uncertainty in LCA.

Need for a Geometric Metric

- **Engineering designers are visual thinkers, therefore a geometric representation of uncertainty is easy to communicate to a designer.**
- **By creating geometric metrics, interrelations (or correlations) among the environmental impacts can be easily understood.**
- **A geometric metric could potentially give an insight into advantages of certain processes under certain conditions, choosing alternatives to make the product more sustainable, thereby reducing the effect on environment**
- **Geometric representation of uncertainty can also be accumulated over multiple process and subcomponents using Minkowski operators or convolutions.**

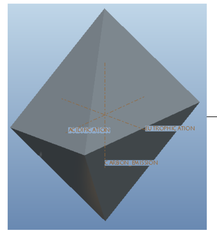
Objective

- **Create a multi-dimensional Geometric Metric for LCA parameters with aleatoric uncertainty for mechanical products and represent it as a bounded space called Sustainability map(S-Map).**

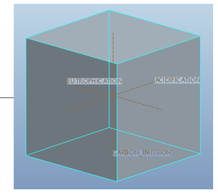
METHOD

- **A Novel geometric metric for the uncertainty in the process parameters is developed using Barycentric co-ordinates and mapped onto a hypothetical space called S-Map (Sustainability Map)**
- **S-Map, a bounded space for multiple process parameters can be accumulated using a mathematical technique called, Minkowski's sum for multiple convex multi-dimensional shapes. The accumulated S-map is the total uncertainty of all environmental impacts of a product life-cycle.**
- **This research focuses on creating an effective algorithm for non-convex to non-convex or non-convex to convex accumulation of multi-dimensional shapes for uncertainty accumulation in LCA**

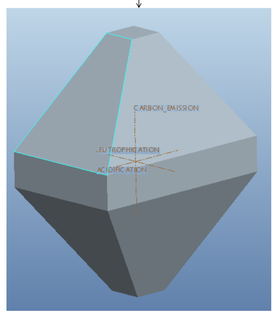
Typical Geometric Metrics



S-Map for Process A



S-Map for Process B



Accumulated S-Map of Process A & Process B

CONCLUSIONS

- **This research creates a novel geometric metric called S-Map to quantify and accumulate the aleatory uncertainty for life-cycle assessment of a mechanical product.**
- **The S-Map is embedded in a tool that can easily be used by designers in order to compare multiple design options for a mechanical product based on environmental impacts and accumulated uncertainty.**
- **New consistent and efficient algorithm is also developed for creating Minkowski sum with non-convex multi-dimensional shapes (S-Maps).**
- **Given known multidimensional distributions of uncertainty in different processes, they can be accumulated using convolutions.**

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