Reduction of End-of-Life Impacts Through Design for Disassembly (DfD)

LMAS

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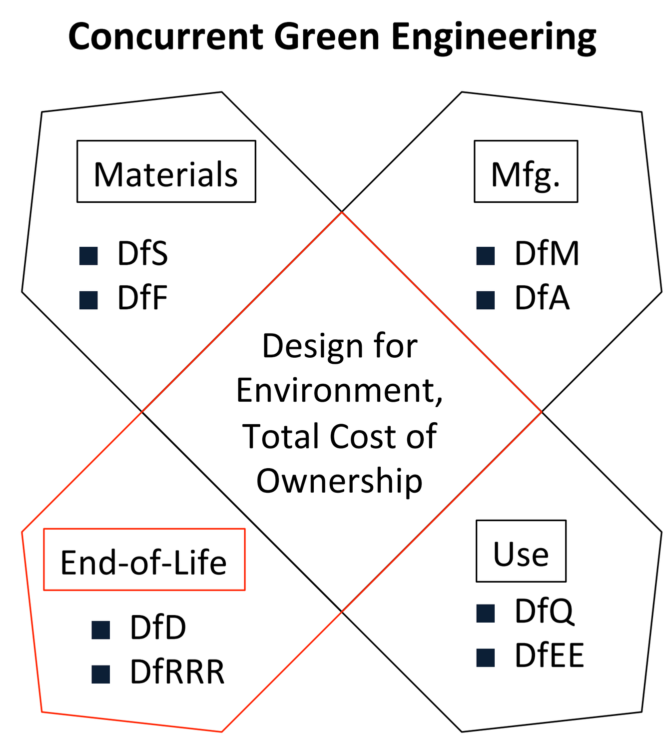
Introduction

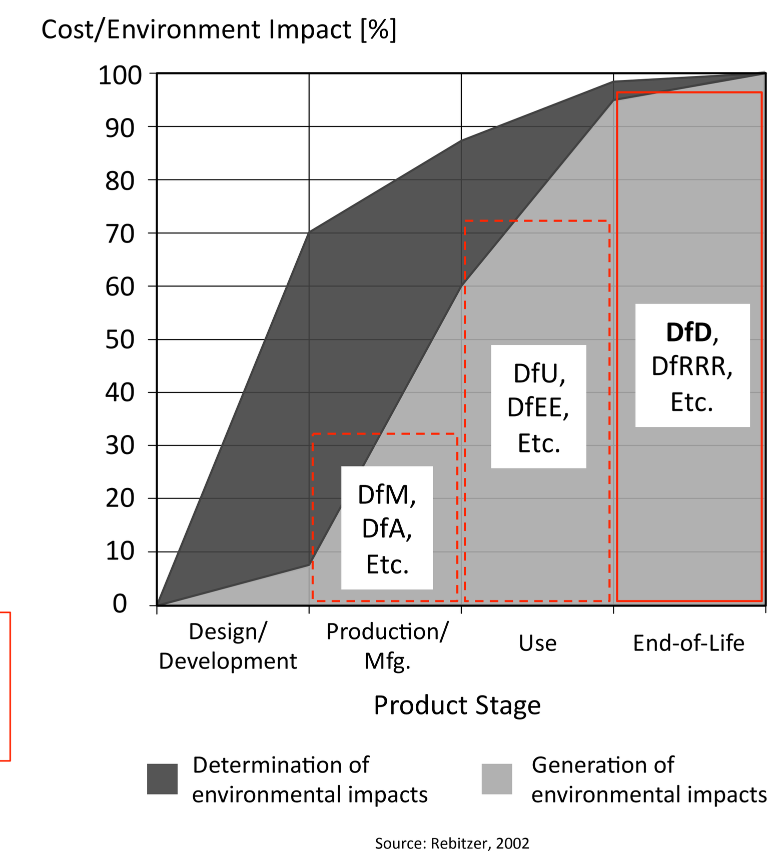
- Achieving product sustainability and lowest total cost of ownership (TCO) requires integrating all aspects of 'Design for X' in green life-cycle engineering design
- Existing green DfX approaches mainly focuses on materials, manufacturing and assembly, and the use phases
- End-of-Life (EoL) phase is often overlooked or neglected due to lack of data and/or high degree of complexity/uncertainty
- Integrating EoL aspects in the design phase can facilitate in a more complete LCA and LCC analysis
- Most common design approach for reducing EoL impacts is Design for Disassembly (DfD)



Motivation

- Potentially greatest environmental and cost burden
- Every product carries material and embedded energy value that can be reclaimed
- Social impacts:
  - Human safety (from landfills)
  - Nuisance: dust, odor, vermin, etc.
  - Local pollution (land, air, water)
  - Land space scarcity
- Other reasons:
  - Government regulation
  - Material scarcity

DfD offers potentially the greatest environmental and cost benefits

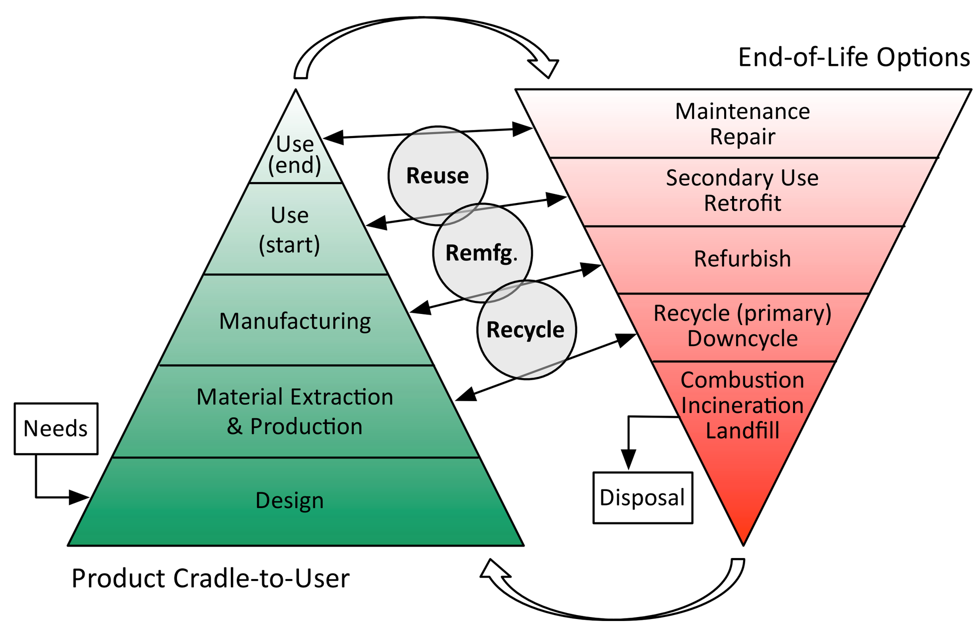


Source: Rebitzer, 2002

End-of-Life Pathways

- Need to identify the appropriate EoL pathway(s) as part of the design process
- Generally better to: reuse → remfg. → recycle
- Challenges:
  - Generally, product $A_{new} \neq$ product A_{used} (contaminated, damaged, worn, etc.)
  - Current EoL infrastructure not well regulated; no standardization
  - Many recycling processes have yet to be development and current ones improved

End-of-Life Option	Objective	Level of Disassembly
Maintenance; Repair	Maintain/Restore working condition	Product Level
Secondary Use; Retrofit	Create secondary functionality	Product/Module Level
Refurbish; Remfg.	Restore quality level as/like new	Module/Part Level
Recycle; Downcycle	Raw material recovery	Material Level
Combustion	Secondary energy generation	Positive value
Incineration	Reduction of solid mass; treatment	Zero value
Landfill	Disposal of unwanted material	Negative value



EoL Pathway Considerations

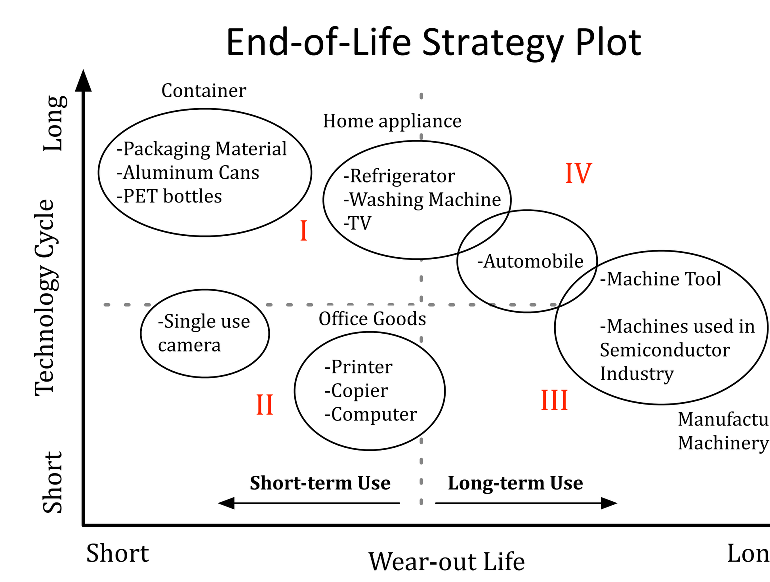
Understanding the EoL system:

- Who owns the product? – Understand the ownership at EoL
- Why do products get thrown away? – Understand the current EoL pathway(s)
- Social/External factors that may influence a particular EoL pathway:
  - Market Competition
  - Trends (e.g. fashion, fads)
  - Technology (e.g. new features)
  - Consumables (e.g. toilet paper)
  - Health/Safety (e.g. bandage)

Key considerations for identifying EoL pathway(s):

- Wear-out life
- Design cycle
- Technology cycle
- Replacement life
- Functional complexity
- Obsolescence

End-of-Life Strategy Plot



Product Category	End-of-Life Scenario
Type I	Material recovery
Type II	Re-mfg.
Type III	Lengthen product life by retrofitting
Type IV	Lengthen product life by maintenance

Source: Masui et al., 2002

DfD Guidelines

DfD design rules	
Factors affecting the disassembly process	**Guides to improve disassembly**
Product structure	Create a modular design Minimize the component count Optimize component standardization Minimize product variants
Materials	Minimize the use of different materials Use recyclable materials Eliminate toxic or hazardous materials
Fasteners, joints and connections	Minimize the number of joints and connections; Make joints visible and accessible; eliminate hidden joints Use joints that are easy to disassembly Mark non-obvious joints Use fasteners rather than adhesives
Characteristics of components for disassembly	Good accessibility; Low weight Robust, minimize fragile parts; Non-hazardous; Preferably unpainted
Disassembly conditions	Design for automated disassembly Eliminate the need for specialized disassembly procedures DfD with simple and standard tools

Source: Bogue, 2002

DfD design rules for metals
Un-plated metals are easier to recycle than plated ones
Low-alloy metals are more recyclable than high alloy ones
Most cast irons are easily recycled
Aluminum alloys, steel, and magnesium alloys are readily separated and recycled from shredder outputs
Contamination of iron or steel with copper, tin, zinc, lead or aluminum reduces recyclability
Contamination of aluminum with iron, steel, chromium, zinc, lead copper or magnesium reduces recyclability
Contamination of zinc with iron, steel, lead, tin or cadmium reduces recyclability

Source: Bogue, 2002

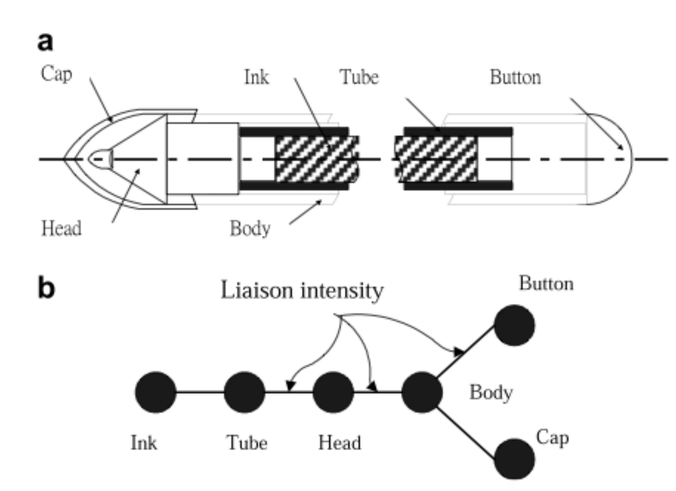
Improving product modularity increases material/component reuse and re-mfg. efficiency and increases ease of repair and serviceability

DfD Modeling

- Formulate relations between parts called "liaisons" that depicts how parts interact and are connected to each other
- Liaison Intensity (LI) of i[th] component (Tseng et al., 2008):

$$LI_i = w_1 \cdot CT_i + w_2 \cdot CB_i + w_3 \cdot TL_i + w_4 \cdot AD_i$$

  - Contact Type (CT)
    - Lower LI for fewer degrees of contact
  - Combination Type (CB)
    - Higher LI for more complex joining
  - Tool Type (TL)
    - Higher LI for more complex disassembly tooling requirements
  - Accessed Direction (AD)
    - Lower LI for higher accessibility
  - w_i: relative weight
  - Additional engineering attributes may be used for more complex products
- Iteration of all valid liaison sequences for optimal disassembly design



a) components of a pen
b) liaison graph of pen

Intensity of contact type

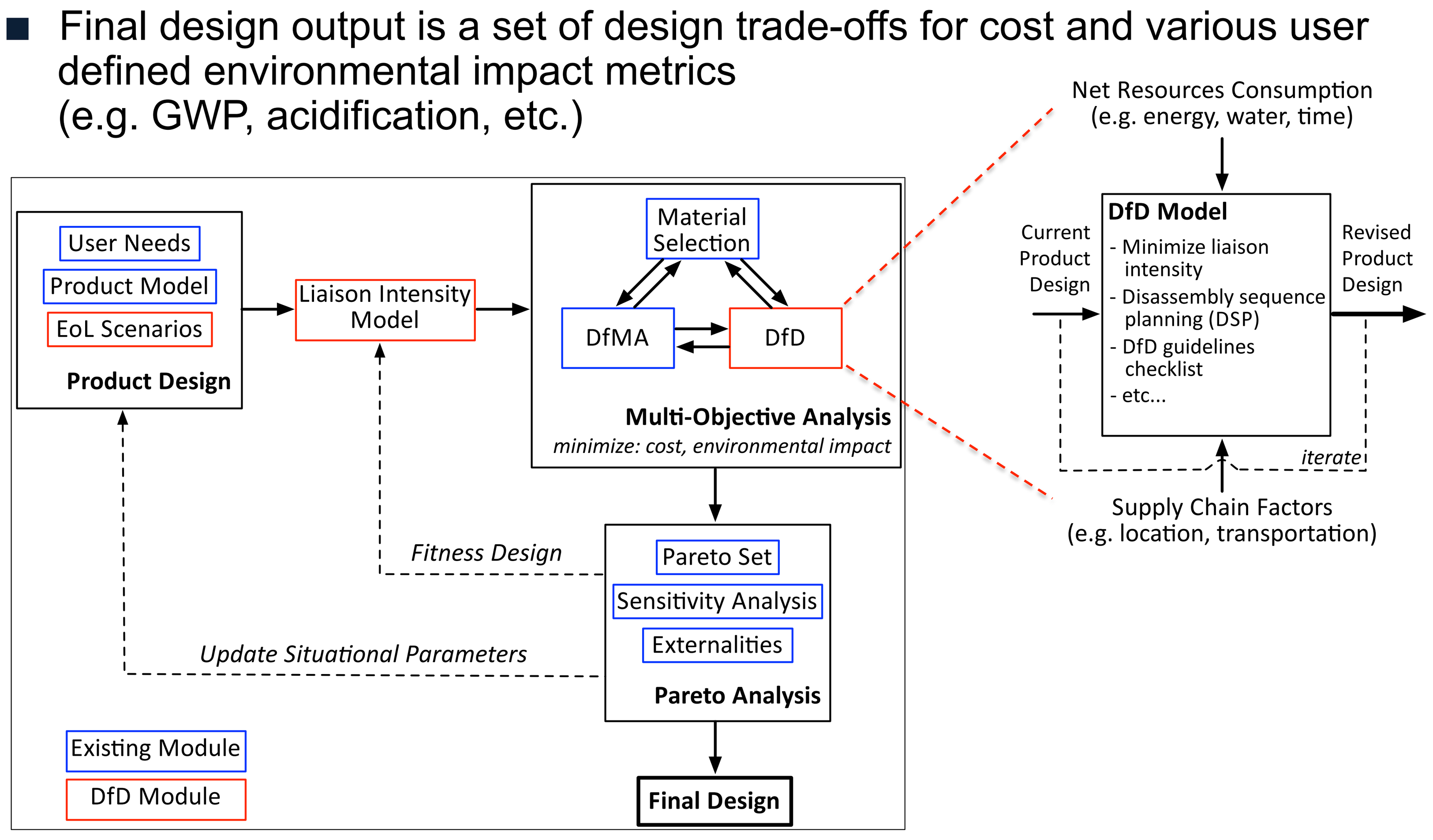
Attribute	Liaison intensity	Description
Point contact	6	The contact part is a point
Line contact	12	The contact part is a line
Single face contact	18	The contact part is a face
Multi-point contact	24	Many points will be contacted
Multi-face contact	30	Many faces will be contacted

Example of CT liaison intensity scale

Source: Tseng et al., 2008

Integration

- Proposed assessment methodology for determining optimal environmental and cost benefits using concurrent green engineering
- Final design output is a set of design trade-offs for cost and various user defined environmental impact metrics (e.g. GWP, acidification, etc.)



Summary & Future Work

- End-of-Life considerations can be equally, if not more important when conducting LCA and LCC analyses
- DfD has emerged as a key discipline in the DfX field for product sustainability and lowest total cost of ownership
- DfD practices can be adopted through a series of relatively simple guidelines and understanding of the EoL system
- Full DfD implementation with DfMA, etc. can be achieved using liaison graphs and the liaison intensity

Future work:

- Develop systematic strategies for choosing preferred EoL pathway
- Integrating DfD design guidelines and EoL system in DfD model
- Developing and customizing more advance engineering attributes for the liaison intensity
- Developing and modeling non-conventional liaisons such as material additive processes (e.g. thin film deposition, coatings) and surface finishes
- Full integration of DfMA and DfD with multi-objective analysis

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