DETC2013-12587

Product Resynthesis as a Reverse Logistics Strategy for an Optimal Closed-loop Supply Chain

8/05/2013

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PRESENTATION OVERVIEW

- Research Motivation
- Research Objectives
- Literature Review
- Methodology
- Results
- Path Forward

Research Motivation

- Over 2 million tons of electronic devices were discarded in the U.S in 2009 (also a global problem)
- Only 15-20% of electronic component based waste is treated with EOL decision-making, with the remainder of these electronics going directly to landfills and incinerators

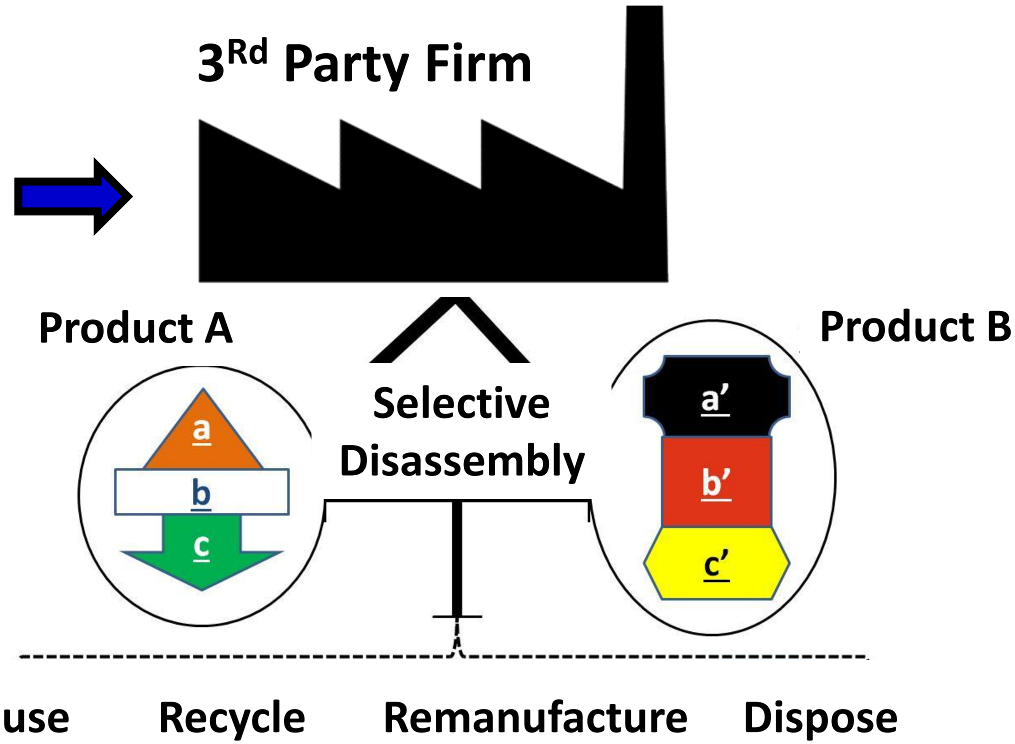
Forward Logistics Methodologies

Original Equipment Manufacturer (OEM)

Retailer

Customer

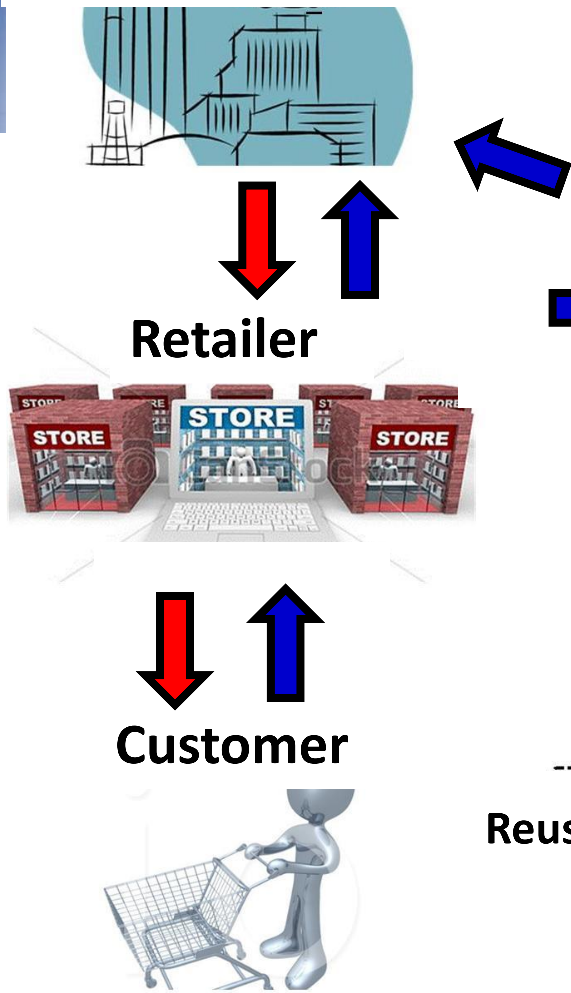
Lambert (1999, 2001), Sosale et al (1997), Rosen (1996), Mangun and Thurston (2002), Pandey and Thurston (2007), Kwak et al (2007), Hammond et al (1998), Kara et al (2005), Lee et al (2001), Behdad et al (2010),

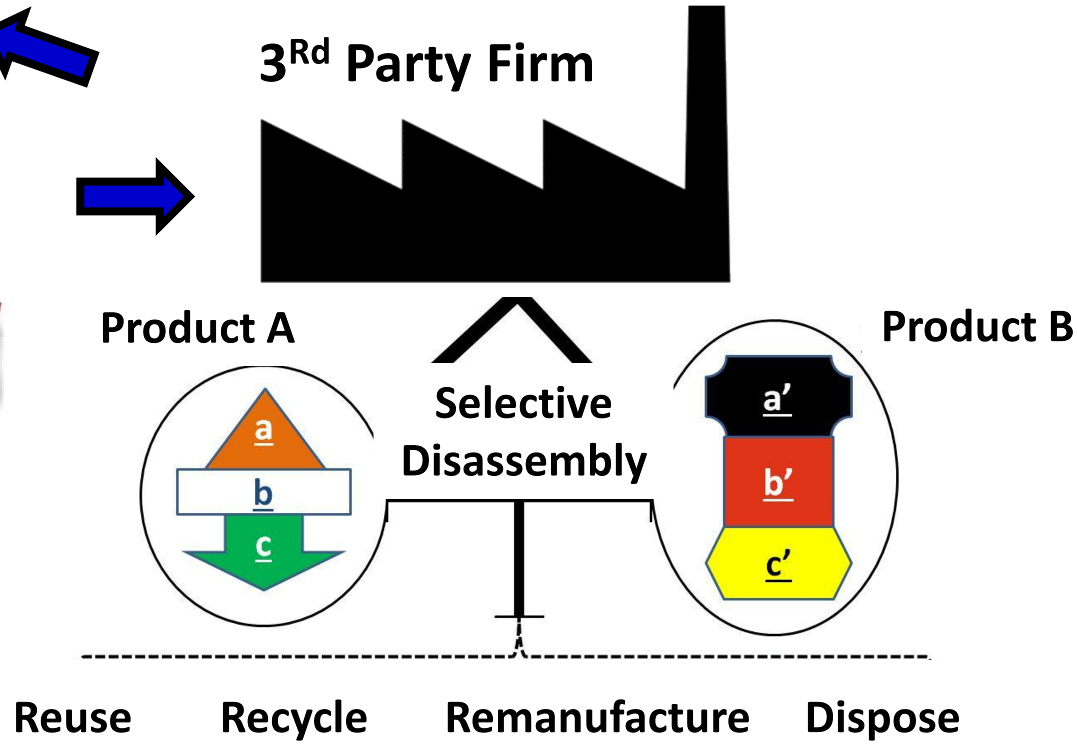


Reverse Logistics Methodologies

Original Equipment Manufacturer (OEM)

- Kopicki et al (1993), Guide et al (2003), Krikke et al (2003), Nagurney and Toyasaki (2005), Schultmann et al (2006), Siegel and Vitaliano (2007), Guide and Wassenhove (2009), Shi et al (2011), Dai and Wang (2012)





Challenges of Existing Methodologies

Original Equipment Manufacturer (OEM)

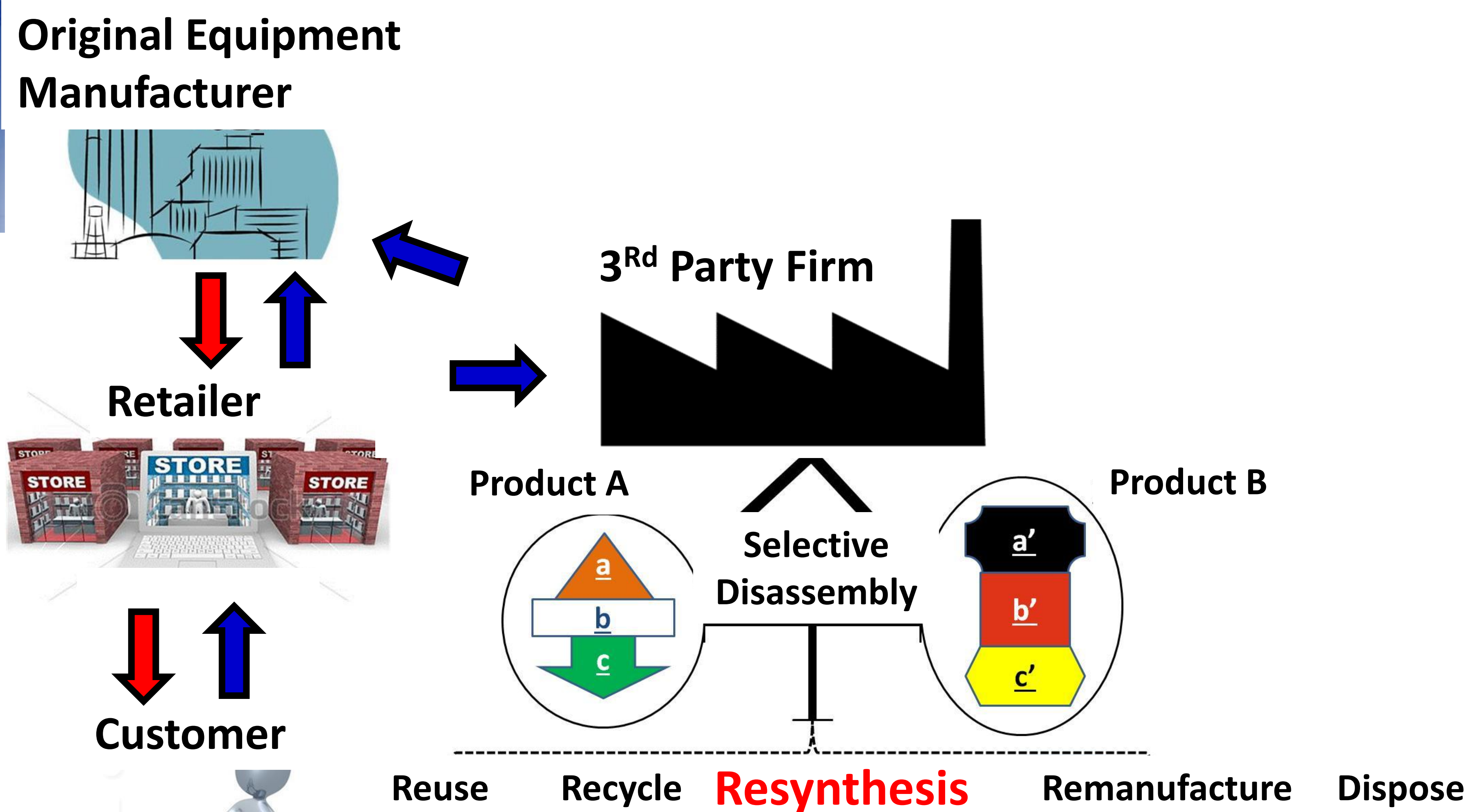
- Low Economic Incentives for the OEM
- Cannibalization of existing products
- Do not fully explore the value of EOL product assemblies/subassemblies

Research Objectives

- Discover latent, previously unknown relationships between End of Life (EOL) assemblies/subassemblies by quantifying their form/function similarities
- Determine candidate End of Life (EOL) assemblies/subassemblies that are suitable for *Product Resynthesis*
- Establish *Product Resynthesis* as a viable EOL strategy for Closed-loop supply chains

Research Methodology

Proposed Methodology



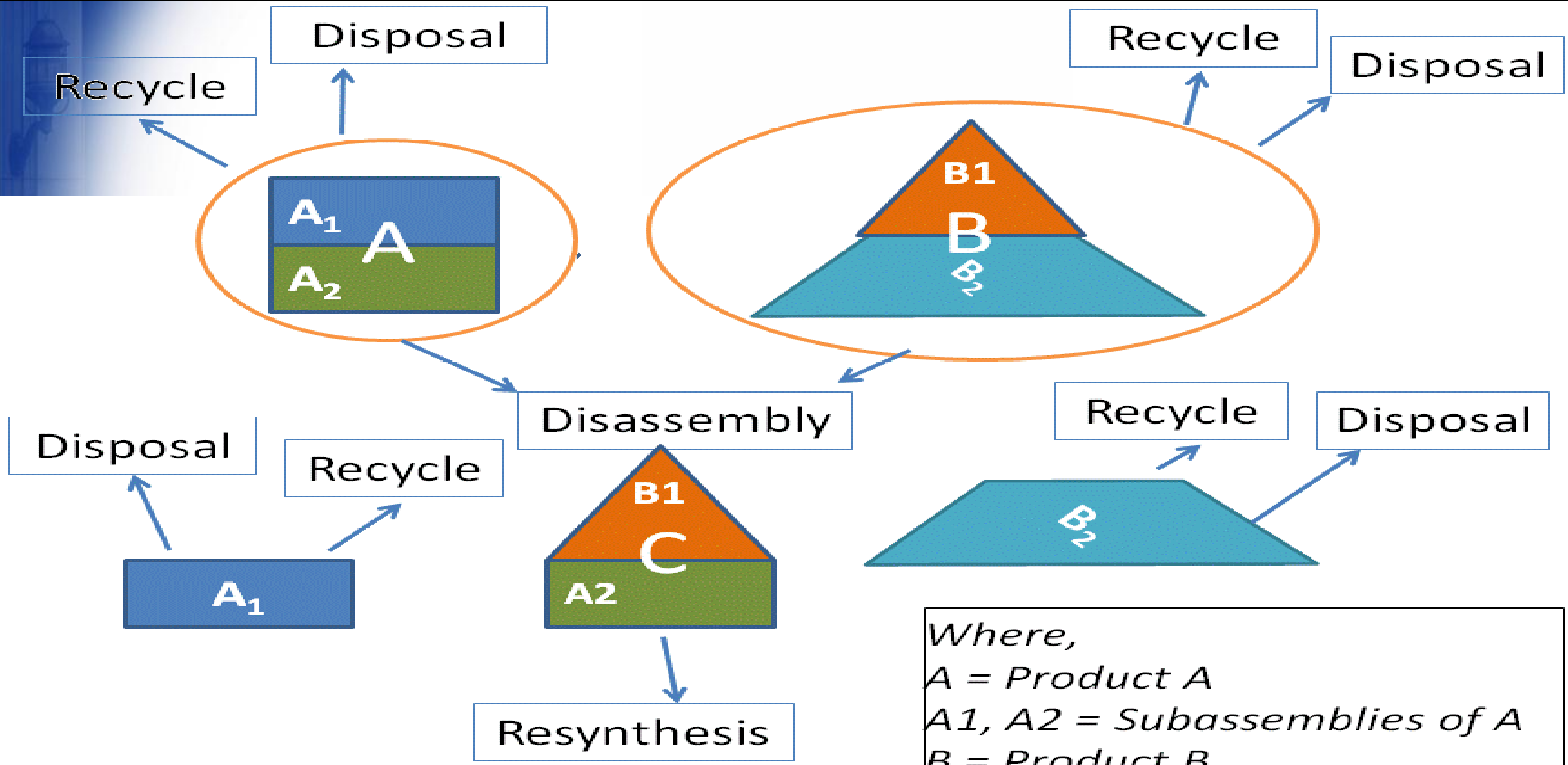
C. Sane, S. Kang, N. Vasudevan, and **C. S. Tucker**, "Product Resynthesis: Knowledge Discovery Of The Value Of End- Of-Life Assemblies And Subassemblies," Accepted: 2013 to appear in ASME Journal of Mechanical Design

What is *Resynthesis*?

Synthesis : The systematic combination of otherwise different elements to form a coherent whole

Resynthesis: The systematic recombination of otherwise different elements to form a coherent whole

Resynthesis as an EOL Strategy

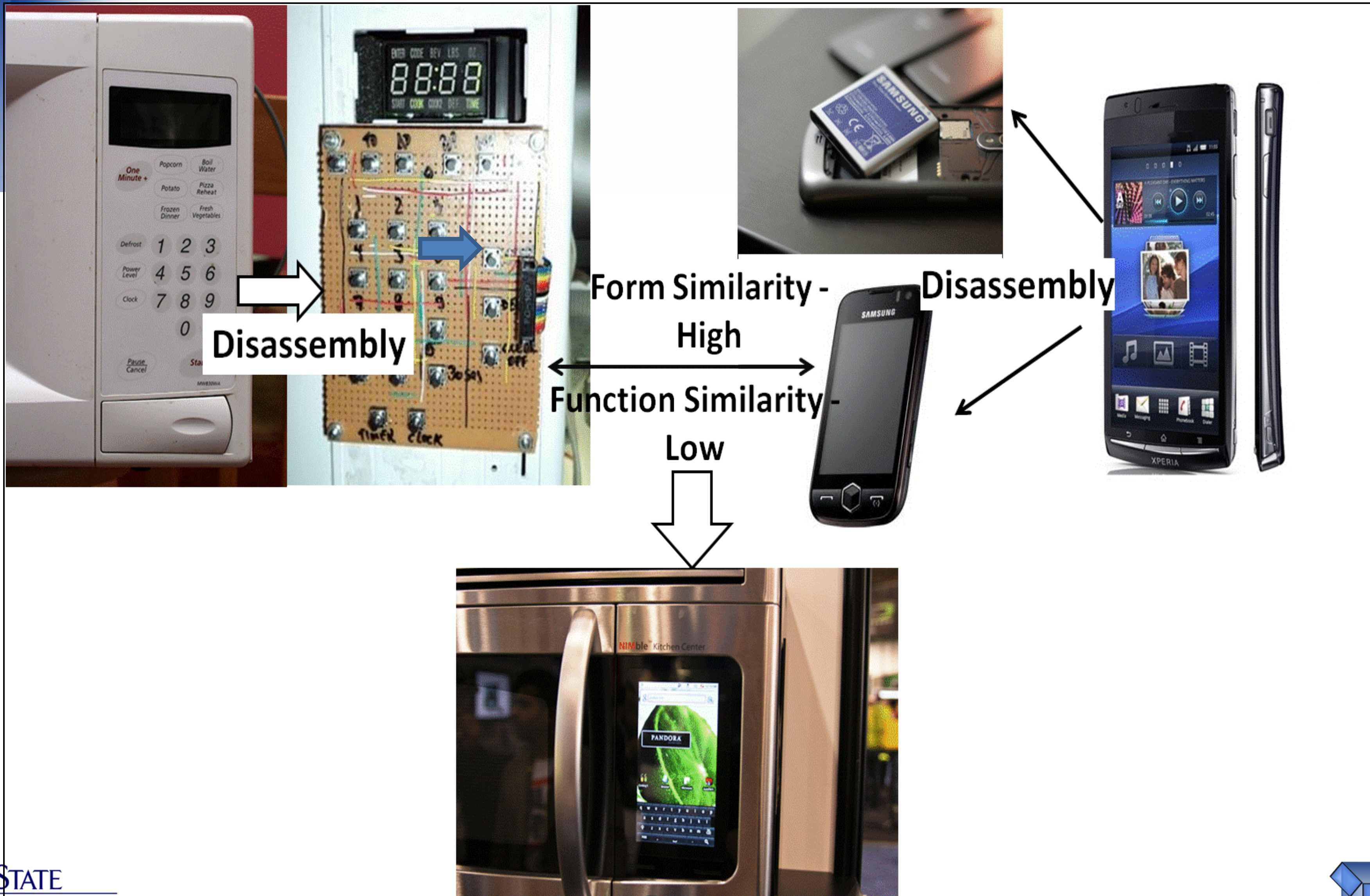


Where,
A = Product A
A1, A2 = Subassemblies of A
B = Product B
B1, B2 = Subassemblies of B

Resynthesis as an EOL Strategy

Operation	Decision				
	Dispose	Reuse	Remanufacture	Recycle	Resynthesize
Collection	X	X	X	X	X
Transportation to disposal centers	X				
Dismantling	X		X	X	X
Refining	X			X	X
Machining			X		X
Disposal of waste	X				
Assembling					X

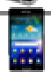
Examples of Product Resynthesis



Proposed Methodology

Data Acquisition → Disassembly Sequence Planning → Quantify Form-Function Similarity → Determine Optimal Resynthesis Candidate

Data Acquisition → Disassembly Sequence Planning → Quantify Form-Function Similarity → Determine Optimal Resynthesis Candidate

	Manufacture	Display Size	Talk Time	Connectivity	Processor	...	...	...	...	...	...	...	...	Price
	Apple	3.5 inches	8 hours	Bluetooth, Wi-Fi, 3G+	1 GHz	...	...	...	...	...	...	...	...	$649
	Samsung	4.5 inches	8.5 hours	Bluetooth, Wi-Fi, 3/4G	1.2 GHz	...	...	...	...	...	...	...	...	$445
	...	...	...	...	...	...	...	...	...	...	...	...	...	...
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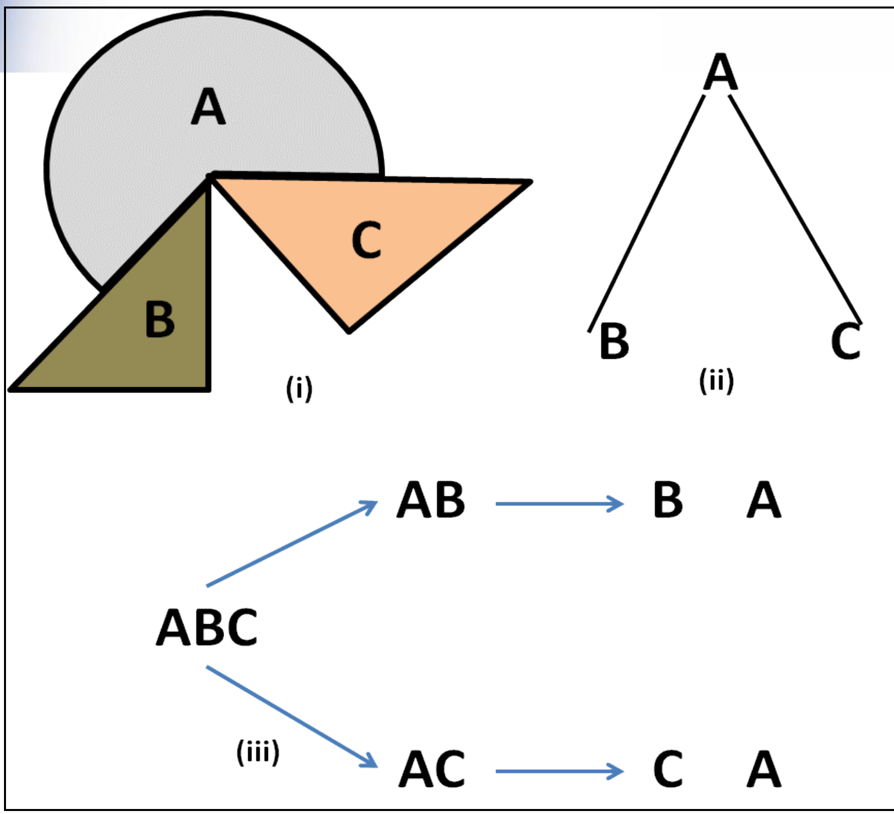
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	Microsoft/Nokia	3.7 inches	9.5 hours	Bluetooth, Wi-Fi, 3G+	1.4 GHz	...	...	...	...	...	...	...	...	$364

Product Database

Object	**Image**	**3D Cad Image (*Form* data)**	***Function* data**
Screwdriver			Screw, shank, handle, rotate, pry lever
Calculator			Mathematical computation, add, subtract, multiply, divide, numbers

Selective disassembly



	0	1	2	3	4
ABC	1	-1	-1	0	0
AB	0	1	0	-1	0
AC	0	0	1	0	-1
A	0	0	0	1	1
B	0	0	1	1	0
C	0	1	0	0	1

Lambert *(1999, 2001)*

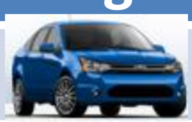
Data Acquisition → Disassembly Sequence Planning → **Quantify Form-Function Similarity** → Determine Optimal Resynthesis Candidate

Domain 1: Design Artifact (j)

Design	Manufacturer	Display Size	Talk Time	Connectivity	Processor	Price
	Apple	3.5 inch	8 hours	Wifi	1GHz	$649

"Bisociative Design" – "Design knowledge discovery across seemingly unrelated domains based on machine learning and natural language processing techniques"

Tucker and Kang (ASME IDETC, 2012)

Design	Manufacturer	MPG	Horsepower	Connectivity	Price
	Ford	50	200 HP	Bluetooth	$20, 000

Domain 2: Design Artifact (k)

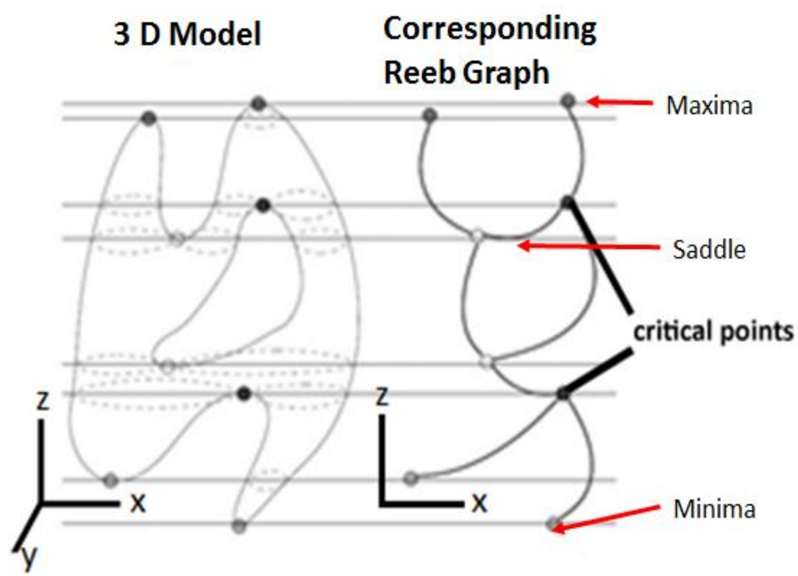
Quantifying Form Similarity

- Reeb Graphs: The degree of similarity is a direct correlation to the level of similarity between the two 3D models

-Doraiswamy et al (2009)

Level set data		
Saddle	Maxima	Minima
1	0	0
2	0	2
3	6	5
.	.	.
1543	1554	1023

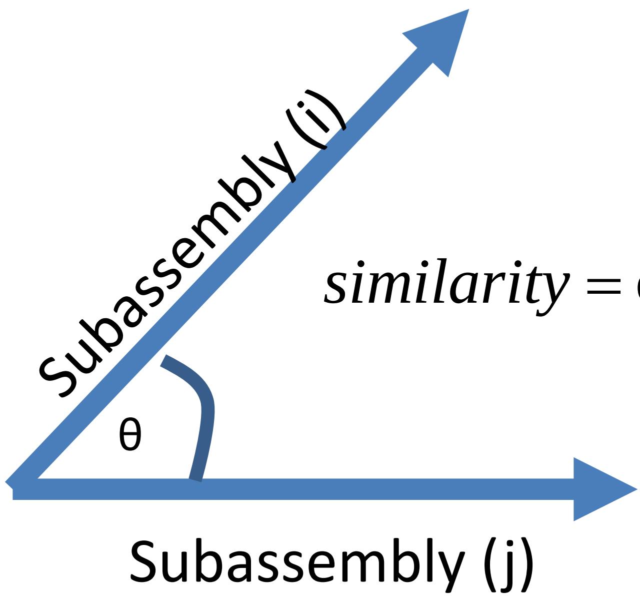
- Sample of generated data.
- Reeb graph comparison – visualization.



Quantifying Function Similarity

		Design Artifact			
		Subassembly 1	Subassembly 2	..	Subassembly N
Functional Descriptive Terms	Term 1	$c_{1,1}$	$c_{1,2}$	..	$c_{1,n}$
	Term 2	$c_{2,1}$	$c_{2,2}$	..	$c_{2,n}$
	.	.	.	..	.
	.	.	.	..	.
	Term M	$c_{m,1}$	$c_{m,2}$	..	$c_{m,n}$

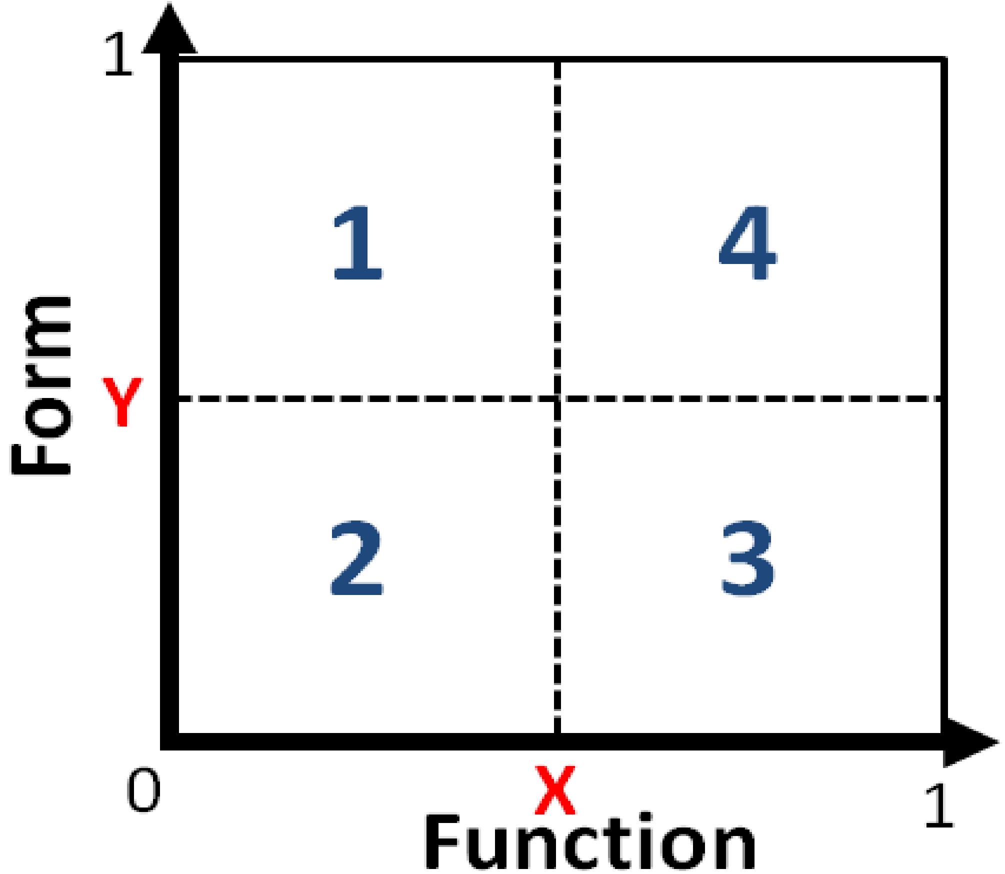
Quantifying Function Similarity *LDA



$$similarity = \cos(\theta) = \frac{D_i \cdot D_j}{\|D_i\| \|D_j\|} = \frac{\sum_{q=1}^{Q} D_{q,i} D_{q,j}}{\sqrt{\sum_{q=1}^{Q} (D_{q,i})^2} \sqrt{\sum_{q=1}^{Q} (D_{q,j})^2}}$$

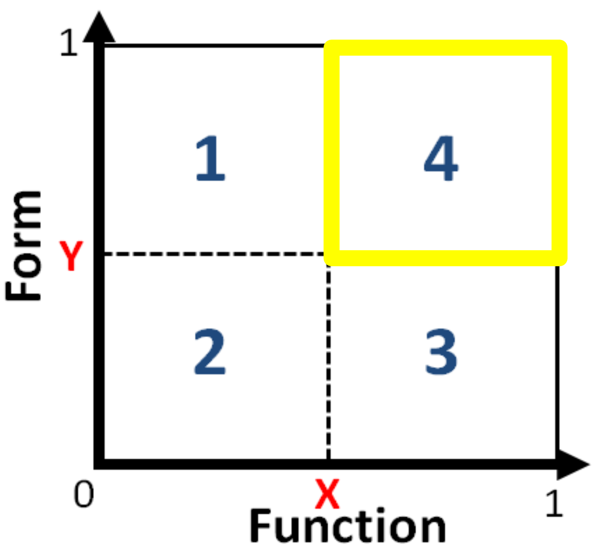
* David M. Blei, Andrew Y. Ng, and Michael I. Jordan. Latent dirichlet allocation. J. Mach. Learn. Res., 3:993–1022, March 2003.

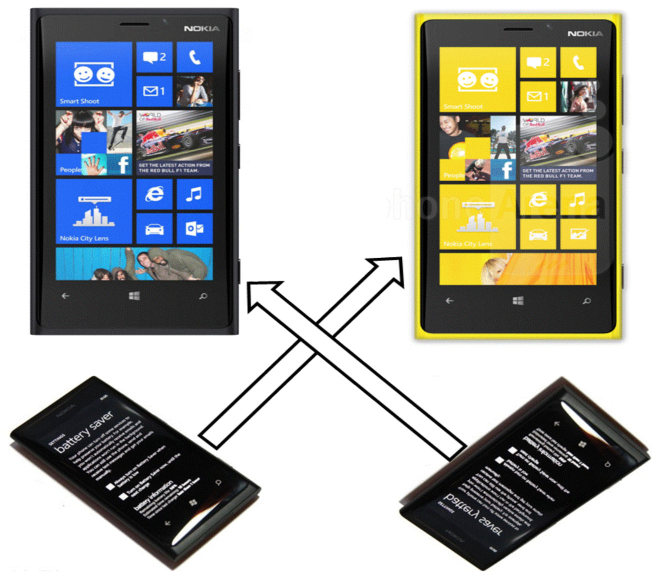
Form-function Mapping



Data Acquisition → Disassembly Sequence Planning → **Quantify Form-Function Similarity** → Determine Optimal Resynthesis Candidate

Quadrant 4: *Form* (high), *Function* (high): Not a high valued candidate for Product Resynthesis

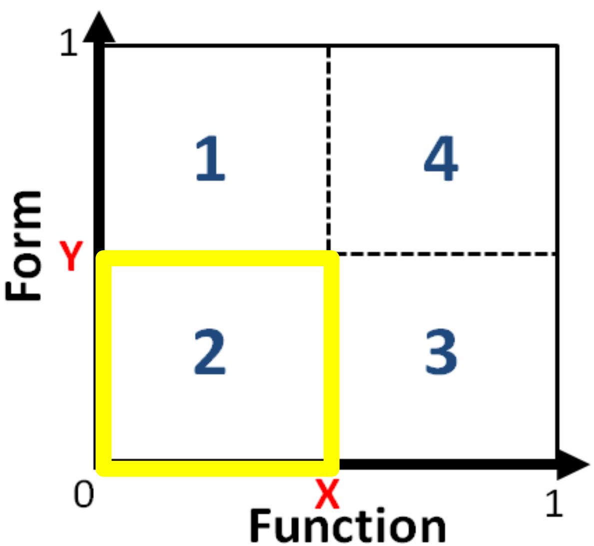


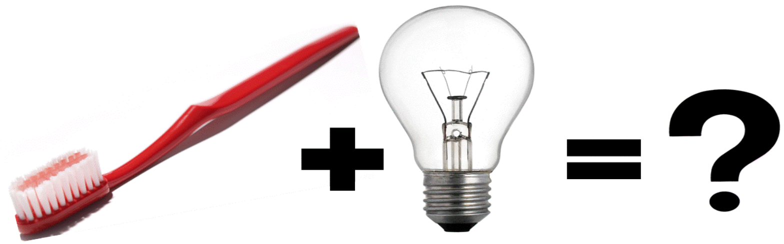


$$\text{profit}_{\text{Resynthesized}} + \text{profit}_{\text{remaining}} \geq \text{profit}_{A} + \text{profit}_{B}$$

Data Acquisition → Disassembly Sequence Planning → **Quantify Form-Function Similarity** → Determine Optimal Resynthesis Candidate

Quadrant 2: *Form* (low), *Function* (low): Higher cost of integration

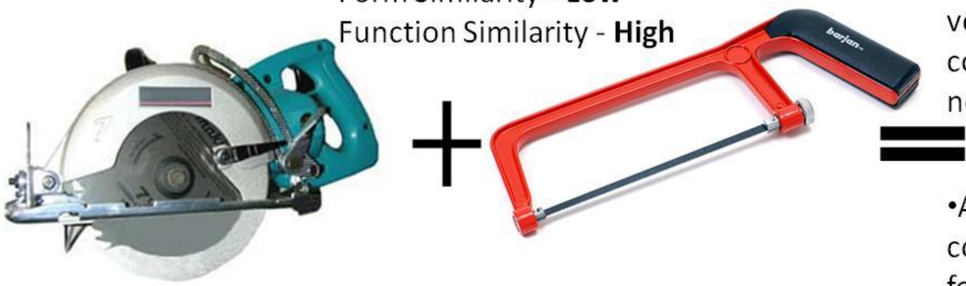




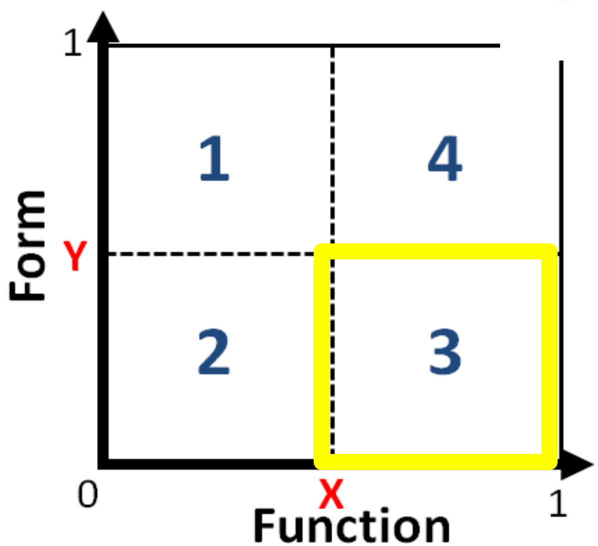
$$\text{profit}_{\text{Resynthesized}} + \text{profit}_{\text{remaining}} \geq \text{profit}_{A} + \text{profit}_{B}$$

Quadrant 3: *Form* (low), *Function* (High): Higher cost of integration

Form Similarity - **Low**
Function Similarity - **High**



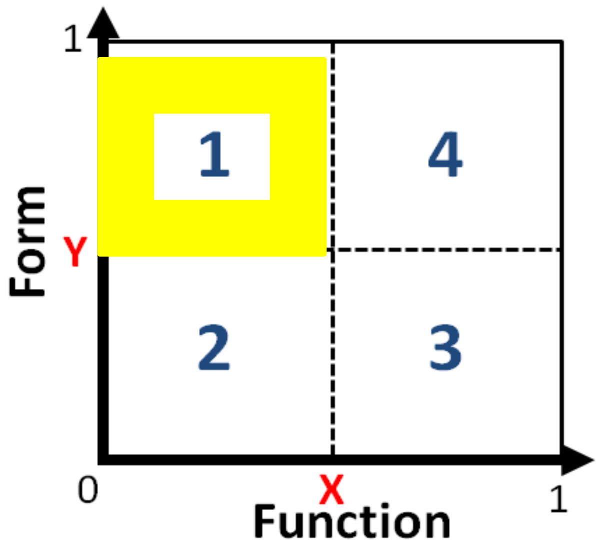
- Since their functions are very similar, their combination if made, will not have any added value
- Also, high cost of combination due to low form similarity

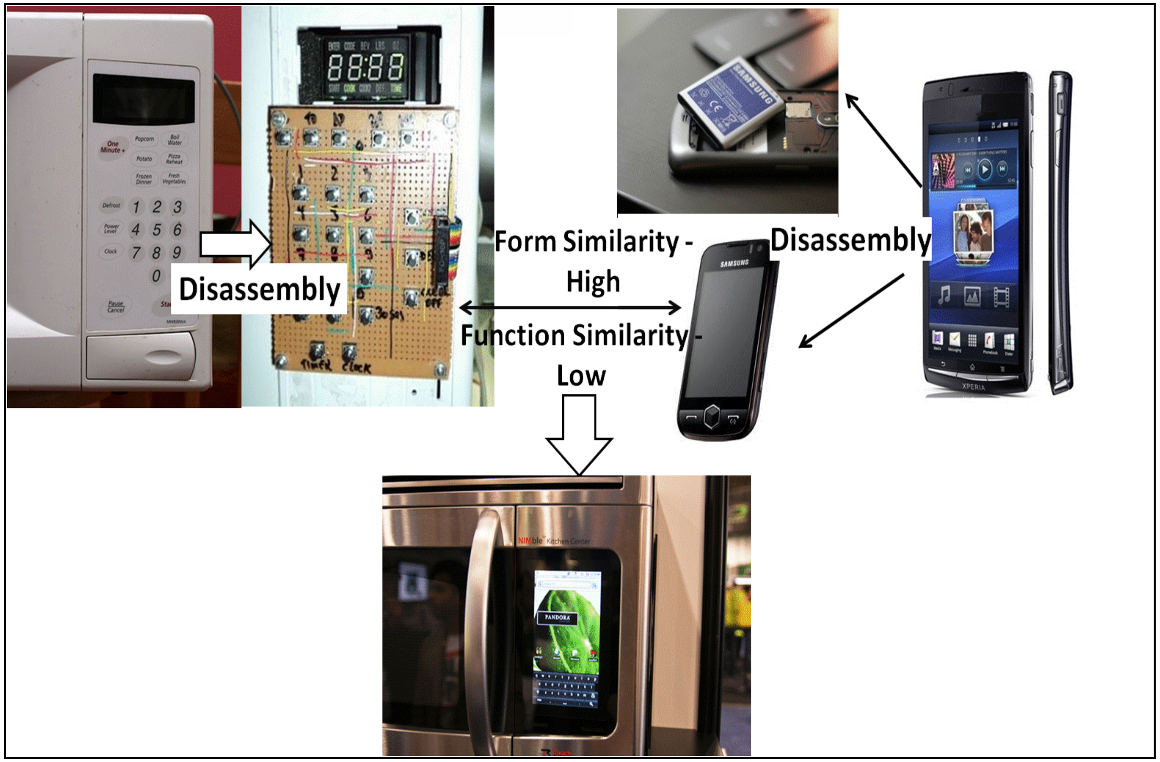


$$\text{profit}_{\text{Resynthesized}} + \text{profit}_{\text{remaining}} \geq \text{profit}_A + \text{profit}_B$$

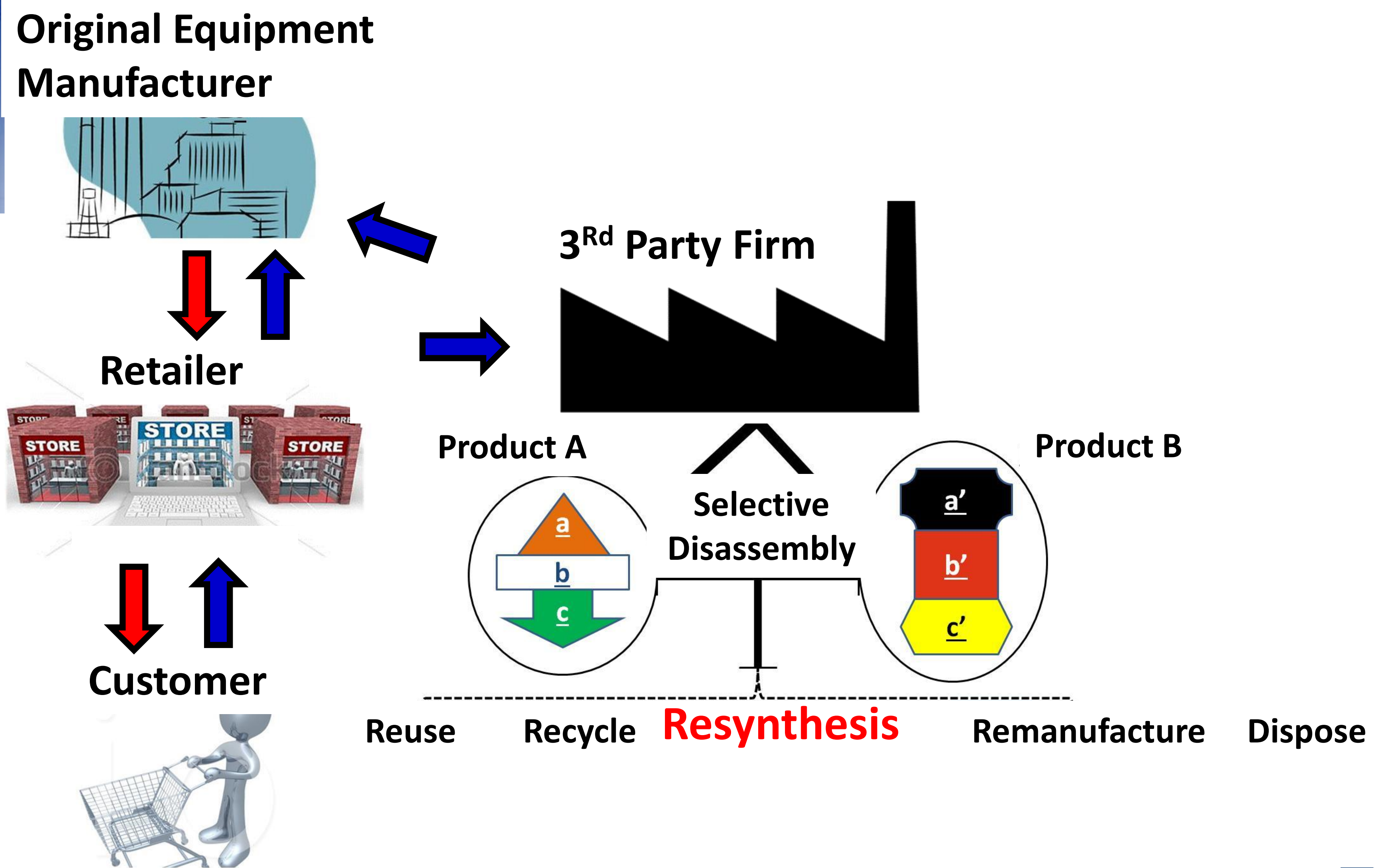
High *Form* and Low *Function* Similarity

Subassembly combinations with High-form and Low-function similarity are economically optimal and hence candidates for resynthesis

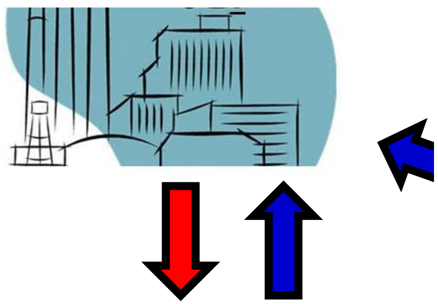




Data Acquisition → Disassembly Sequence Planning → Quantify Form-Function Similarity → **Determine Optimal Resynthesis Candidate**



Original Equipment Manufacturer



$$\pi_M = \{\sum_{i=1}^{N} D(p_i) \times (w_i - c_i)\} + \{\sum_{i=1}^{N} \lambda_i \times \mu_i \times D(p_i) \times (z_i - v_i)\} + \{(\sum_{i \varepsilon I} w_i - s - c_i) * D(new)\}$$

Retailer

$$\pi_R = \{\sum_{i=1}^{N} D(p_i) \times (p_i - w_i)\} + \{\sum_{i=1}^{N} \lambda_i \times D(p_i) \times (r_i - a_i)\}$$

Data Acquisition → Disassembly Sequence Planning → Quantify Form-Function Similarity → **Determine Optimal Resynthesis Candidate**

3^{Rd} Party Firm

$$\pi_{3P} = \{ \sum_{i=1}^{N} \lambda_i \times \mu_i \times D(p_i) \times (v_i - u_i) \} - \{ r_i \times \lambda_i \}$$
$$+ \{ (s+t) \times \beta \times \sum_{i=1}^{N} (1-\mu_i) \times \lambda_i \times D(p_i) \} +$$
$$\{ \sum_{i=1}^{N} (1-\beta) \times (1-\mu_i) \times \lambda_i \times \alpha_i \times h_i \times D(p_i) \}$$
$$+ \{ \sum_{i=1}^{N} \gamma \times (1-\beta) \times (1-\mu_i) \times \lambda_i \times (1-\alpha_i) \times h_i \times D(p_i) \}$$

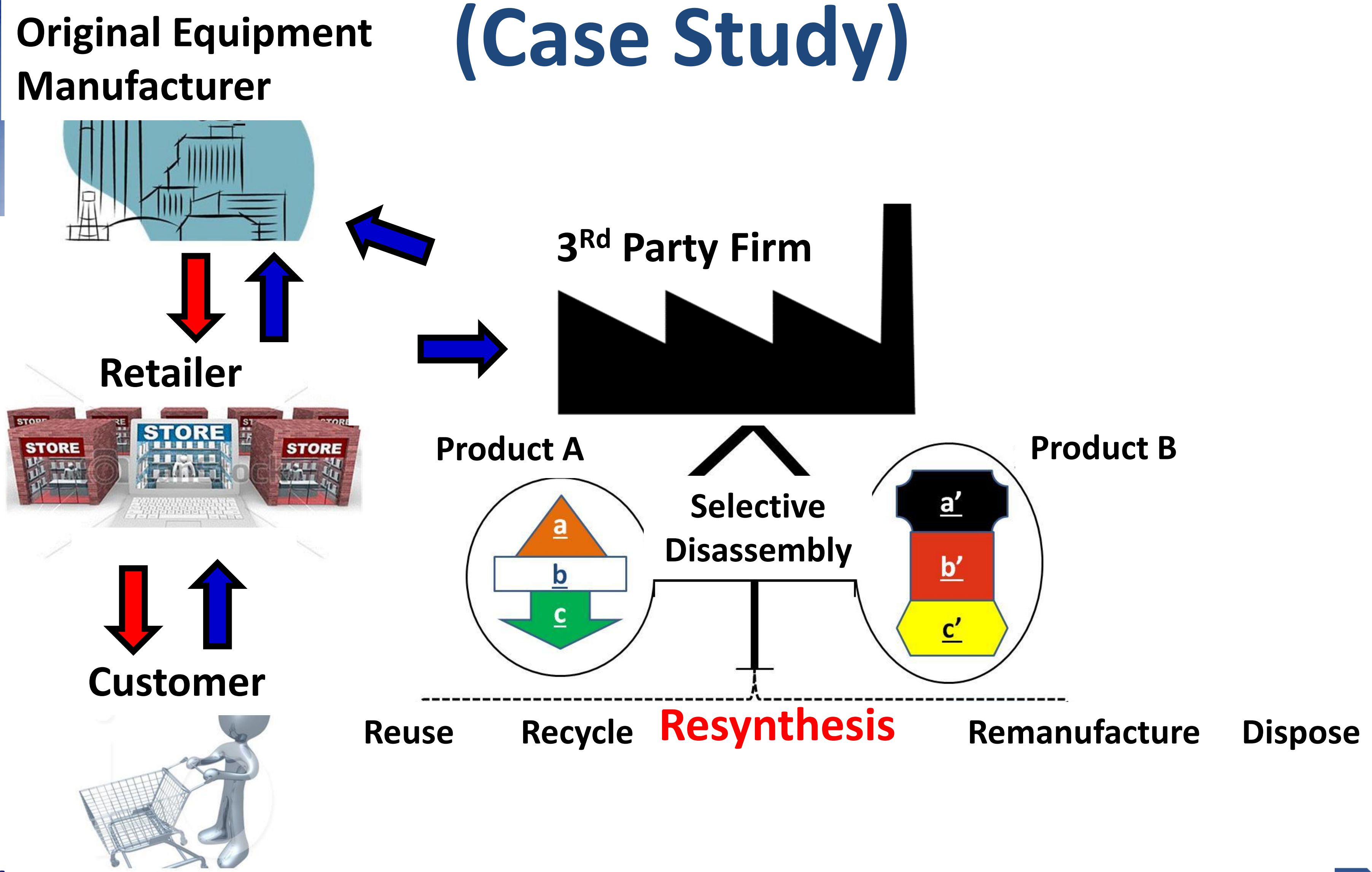
Case Study


STAPLES
The Office Superstore
Copy Center
Pack & Ship
STAPLES
The Office Superstore
Technology

Model Assumptions

- Assemblies/subassemblies have similar reliabilities
- OEMs used in the case study were assumed to manufacture a single product

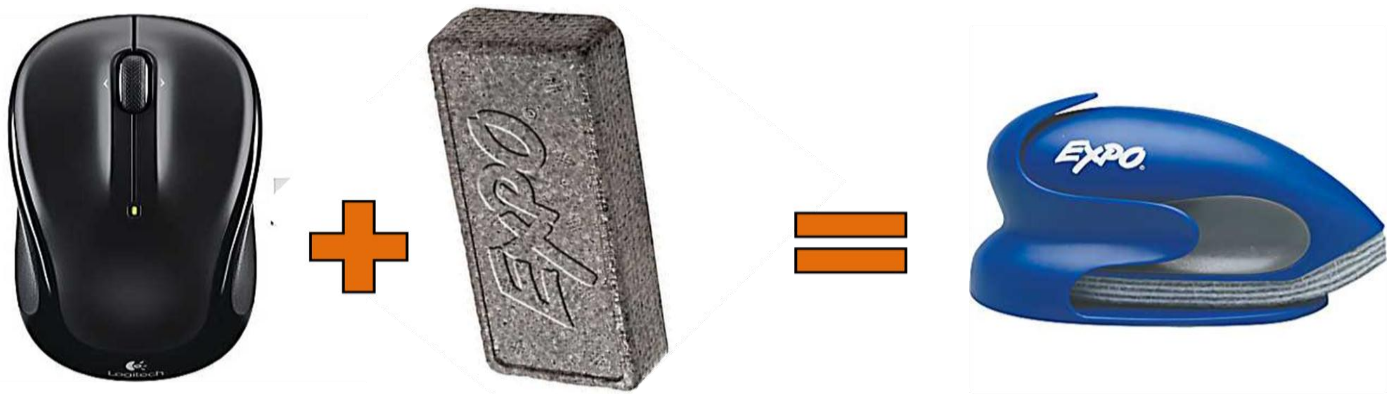
Closed-loop Supply Chain (Case Study)



Candidate Subassemblies for Resynthesis

Component		Eraser casing - B'	Eraser head - A'	A'B'
Mouse top - A	form	0.282	0.074	0.300
	function	0.480	0.060	0.270
Microchip - B	form	0.130	0.129	0.130
	function	0.020	0.010	0.000
Mouse base - C	form	0.159	0.452	0.156
	function	0.320	0.230	0.350
AB	form	0.282	0.074	0.300
	function	0.060	0.020	0.040
AC	form	0.301	0.452	0.377
	function	0.350	0.230	0.360
BC	form	0.159	0.449	0.163
	function	0.170	0.140	0.200

Resynthesized product



Results and Discussion

With Resynthesis

Conclusion & Future work

- The new EOL option, *Resynthesis* is introduced

- Resynthesis has the potential to add to the profit that the corresponding OEM and other players make

- A 3rd party firm is not only capable of handling the reverse logistics but also post recovery alternatives

Acknowledgement & References

Contributors:

• D.A.T.A. Lab: Chinmay Sane, Conrad S.Tucker

References

[1] Arthur Koestler. The Act of Creation. Penguin (Non-Classics), June 1990

[2] H. Bashir and V. Thomson. Estimating design complexity. Journal of Engineering Design, 10(3):247–257, 1999.

[3] O. Benami and Y. Jin. Creative simulation in conceptual design. In Proceedings of ASME Design Engineering Technical Conferences and Computer and Information in EngineeringConference DTM 34023. ASME, 2002.

[4] M. Hilaga, Y. Shinagawa, T. Kohmura, and T.L. Kunii. Topology matching for fully automatic similarity estimation of 3d shapes. In SIGGRAPH '01 Proceedings of the 28th annual conference on Computer graphics and interactive techniques, pages 44–47, 267, Aug 2001

[5] S. K. Moon, S. R. T. Kumara, and T. W. Simpson. Data mining and fuzzy clustering to support product family design. In Proceedings of DETC 06, 2006 ASME

Questions