Examining Supply Chain Drivers for AM Adoption

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Agenda

- Research objectives
- Industry project
- Penn State project
- Observations on the importance of the materials supply chain
- Conclusions/Questions

Research Objectives

Motivation:

- Additive manufacturing is everywhere in the popular press!

Research question:

- When is AM preferred to traditional manufacturing?

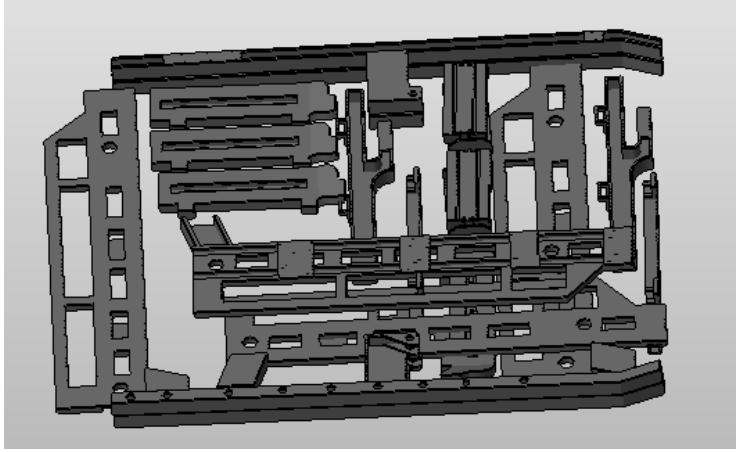
Approach:

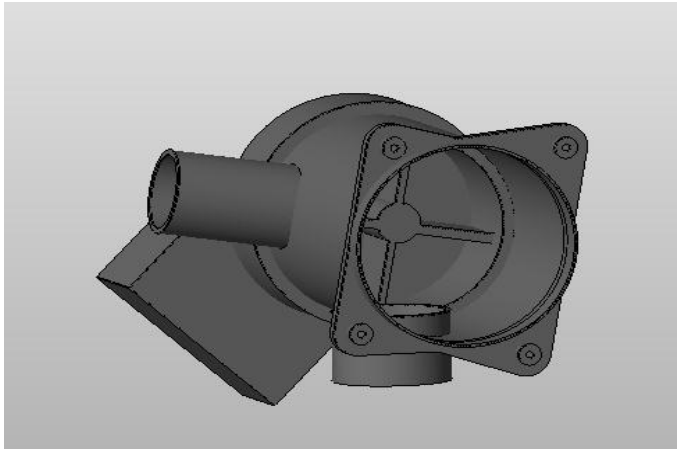
- Model representative supply chains

Industry Project (1/3)

- “The new software-defined supply chain” - industry white paper

- Took four products, reverse engineered:
  - Washing machine
  - Mobile phone
  - LCD TV
  - Hearing aid





Industry Project (2/3)

- Collected wide variety of cost information on machines and materials
- Forecasted costs 5 and 10 years out

MACHINES	Present	In 5 years	In 10 years
Objet 1000	$xxx.xx	$xxx.xx	$xxx.xx
EOS P800	$xxx.xx	$xxx.xx	$xxx.xx
EOS P385	$xxx.xx	$xxx.xx	$xxx.xx
Vx1000	$xxx.xx	$xxx.xx	$xxx.xx
Vx4000	$xxx.xx	$xxx.xx	$xxx.xx
sPro Plastic 230	$xxx.xx	$xxx.xx	$xxx.xx
Fortus 900mc	$xxx.xx	$xxx.xx	$xxx.xx
•	•	•	
•	•	•	
•	•	•	

MATERIALS	Present	In 5 years	In 10 years
Objet support	$xxx.xx	$xxx.xx	$xxx.xx
Objet Vero Black	$xxx.xx	$xxx.xx	$xxx.xx
Objet Durus White	$xxx.xx	$xxx.xx	$xxx.xx
PA2200	$xxx.xx	$xxx.xx	$xxx.xx
PMMA	$xxx.xx	$xxx.xx	$xxx.xx
•	•	•	
•	•	•	
•	•	•	

Industry Project (3/3)

- Attempted to evaluate future supply chains of the different industries

- Personal observations from an AM novice:

1) Materials are expensive!

2) Bulky products are expensive and time-consuming to build

3) Unscientific conclusion – mass-produced, undifferentiated products are not good candidates for AM adoption

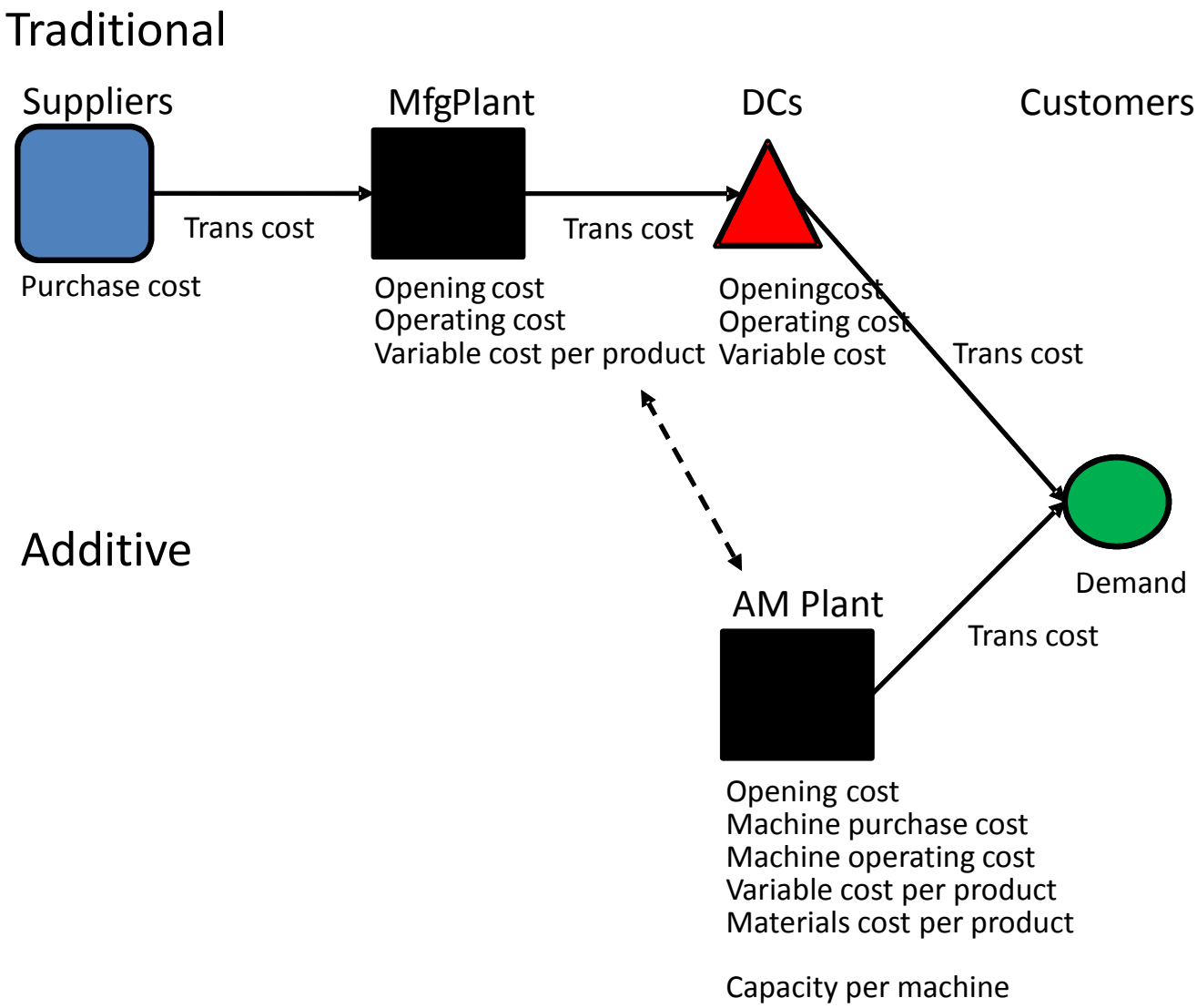
These are personal obervations,

not indicative of anyone else's!

Penn State project

- Given the fundamental differences between AM and traditional manufacturing:
- **When is an AM supply chain preferred to a traditional supply chain?**
- **What are the most important factors that drive AM adoption?**

Approach


Traditional
Suppliers
MfgPlant
DCs
Customers
Trans cost
Trans cost
Purchase cost
Opening cost
Operating cost
Variable cost per product
Openingcost
Operating cost
Variable cost
Trans cost
Additive
AM Plant
Demand
Trans cost
Opening cost
Machine purchase cost
Machine operating cost
Variable cost per product
Materials cost per product
Capacity per machine

Approach cont'd

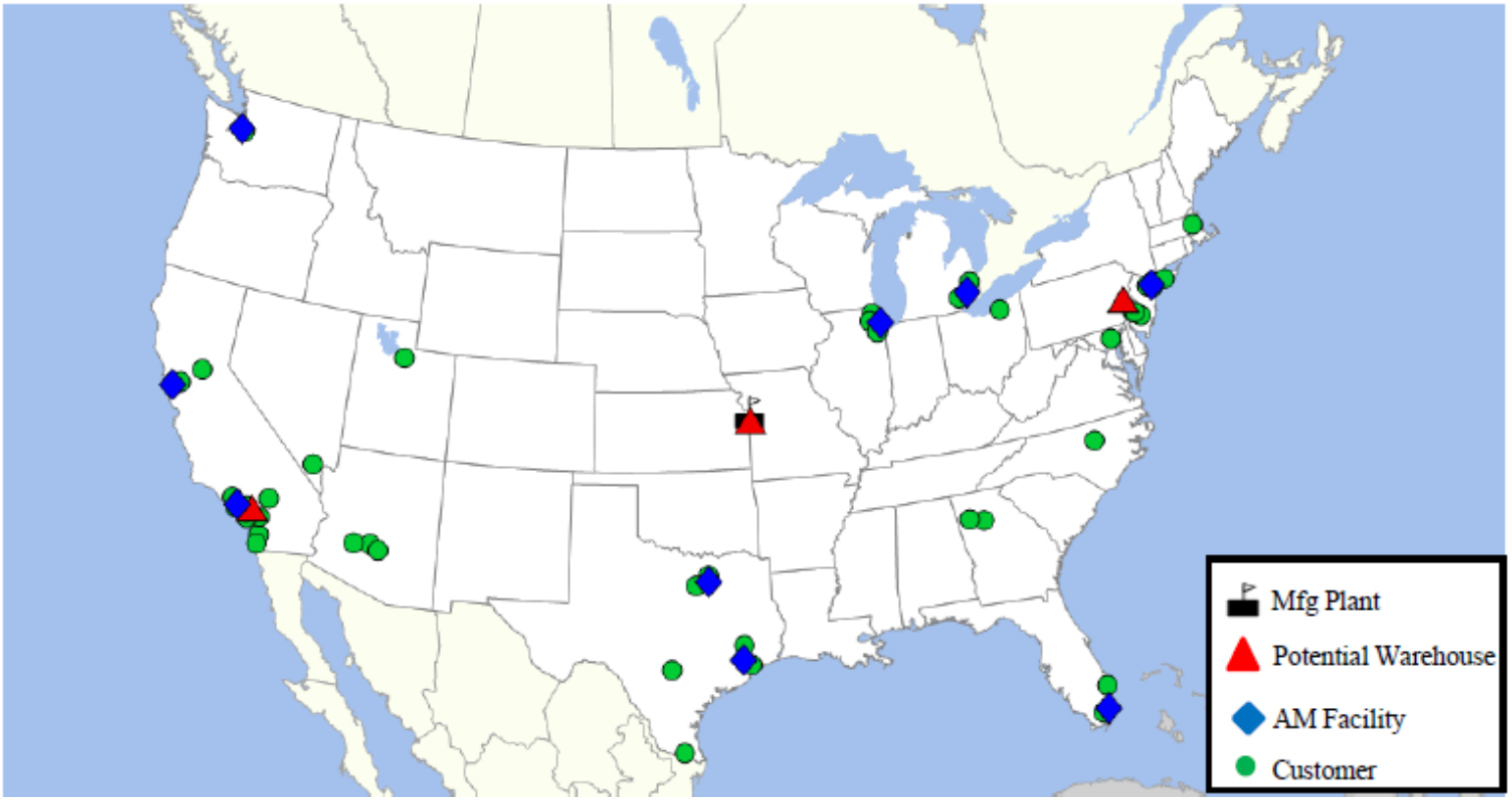
- Two-stage stochastic optimization model
- First stage decision: open and operate mfg plant or AM plant(s)
- Second stage: observe material cost, AM machine capacity, meet demand with lowest cost

Assumptions

- Consider the product is the same whether it is made via AM or traditionally
- No lead time advantages for either process
- AM machines are not used to make other products

Supply Chain Instance

Hypothetical, not based on actual



Scenario Regimen

- 8 critical parameters

Parameter	Low Estimate		High Estimate
TRADITIONAL			
Plant-product variable cost	$ 1.00	$ 5.50	$ 10.00
Plant operating cost	$ 200,000		$ 400,000
Plant opening cost	$ 500,000		$ 1,000,000
ADDITIVE			
Hours per product (stochastic)	0.17		1.7
AM machine operating cost	$ 10,000		$ 100,000
AM machine purchase cost	$ 100,000		$ 1,000,000
Material cost per KG (stochastic)	$ 10		$ 100
Material usage per product	0.10		1.00

- Parameters run over 6 demand ranges: 500 units to 1,000,500 units for a 5 year time frame

- ~2300 scenarios

Logistic Regression Model

- Generated “pseudo-data”
  - Classified supply chain as a “1” when AM is cheaper, “0” when traditional is cheaper

- Fit a binary logistic regression model to predict AM or traditional

$$P(Y_i = 1) = exp(X_i \beta_i) / [1 + exp(X_i \beta_i)]$$

- Dependent variable (Y): AM or traditional supply chain?
- Independent variables:
- Demand
- AM build time
- AM material cost per product
- AM machine purchase cost
- Traditional variable cost
- Traditional plant operating cost
- Traditional plant opening cost

Most important factors based on standardized coefficients…

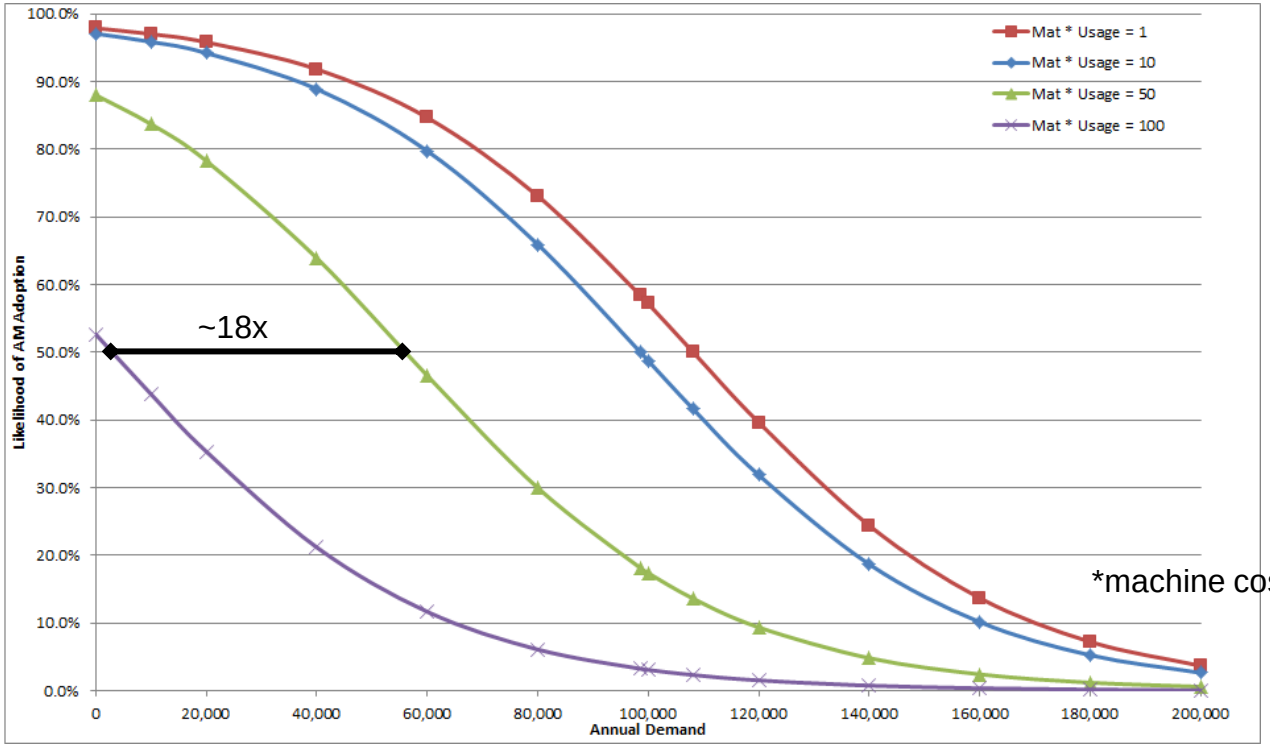
Predictor	Standardized Coef
Total Demand	-0.53
AM processing time	-0.36
AM material cost per product	-0.33
AM machine purchase cost	-0.21
Plant-product variable cost	0.14
AM machine operating cost	-0.12
Plant operating cost	0.05

Most important factors

- Demand
  - AM has been recognized as advantageous for low volume production
  - As demand increases, more likely traditional
- Build time
  - Seems as though this will be difficult to improve?
- AM materials cost
  - Significant possibility for decline in prices
- AM machine cost
  - Possible scale economies

Impact of cost of materials

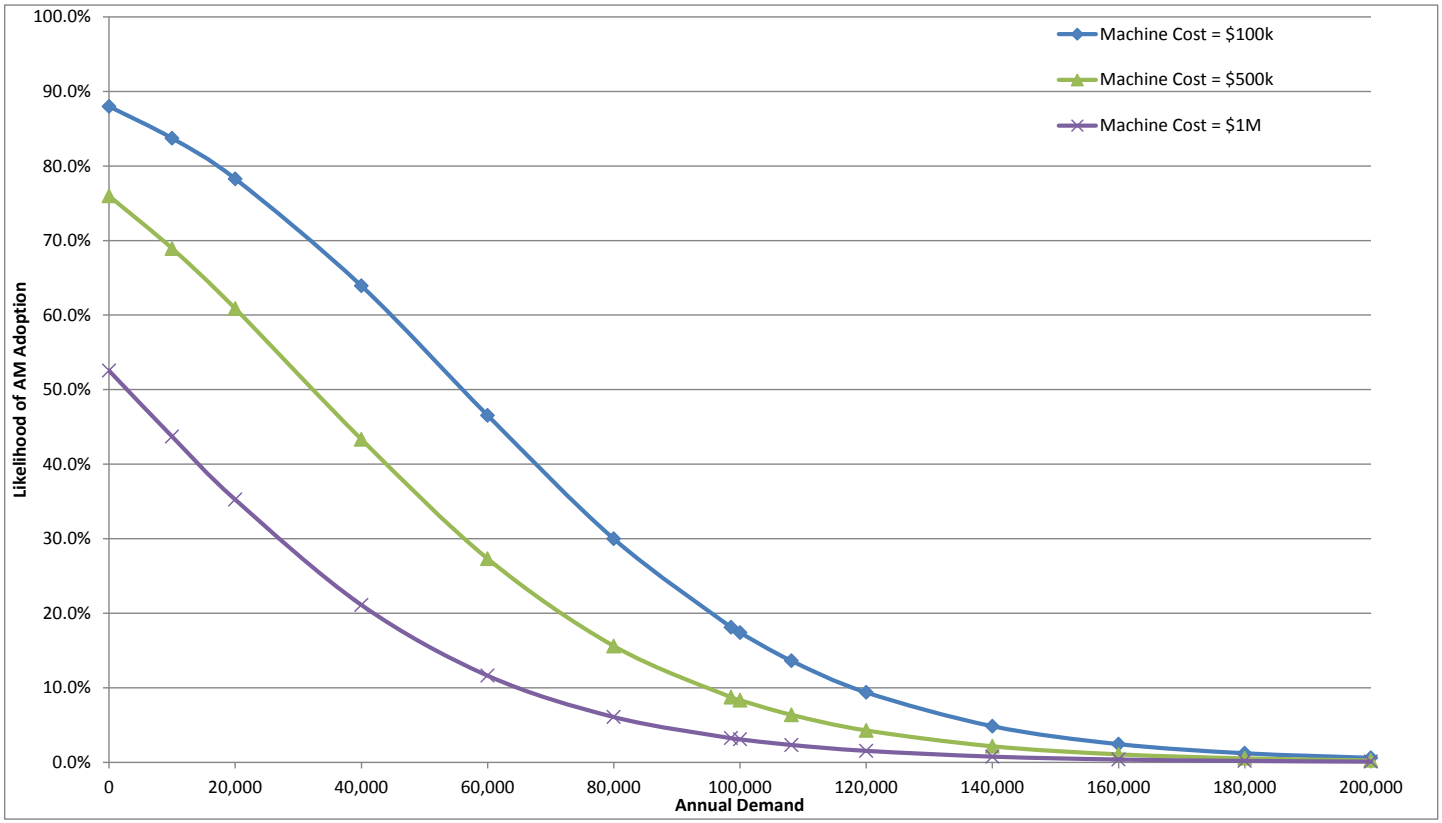
- Used the 50% threshold as a “tipping point”
- Halving cost from $100 per kg to $50 per kg increases tipping point from 3k to 56k units



*machine cost = $100k

Impact of cost of machines

- Halving cost from $1M per machine to $500k per machine increases tipping point from 3k to 32k units



Cost of AM materials compared to traditional?

- Can be very expensive: AM polymers 53 to 104 times more expensive than injection molding equivalent

  – Wohlers and Caffrey, RAPID Conference Brochure, 2013

- Published studies have ranges from 7 to 15 times more expensive for metals

WHY?

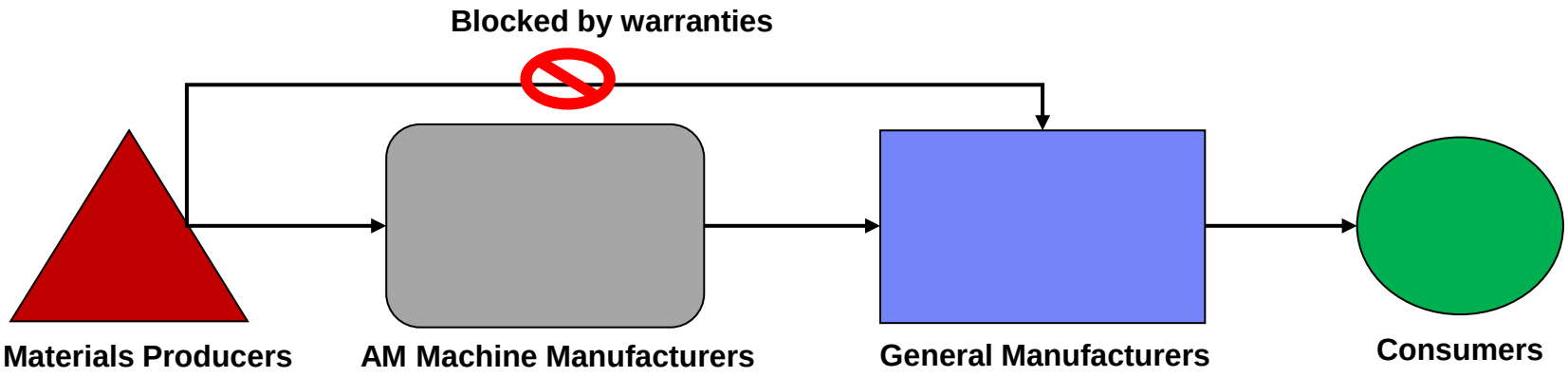
- An extra step beyond traditional materials processing
- Relatively low demand
- Equipment manufacturers control the materials “certified” on their equipment
- Materials are not standardized with multiple producers competing for business

Standardized Materials

"Another concern: Equipment-sales growth has outpaced that of materials for at least the past six quarters. That also matters because, like the razor-blade business model, **sales of printers are meant to generate bigger sales of higher-margin materials.** [3D printer manufacturer] says sales of materials for newer-model printers, **which don't allow use of third-party materials**, are increasing faster than the overall rate. Yet these still lag behind overall printer sales. **Weak materials sales could jeopardize [3D printer manfuacturer's] 2013 earnings target.** To reach it, operating-profit margins in the second half must expand to roughly 40% from the first half's 24%, Mr. Drab estimates."

-*The Wall Street Journal, September 2013*

Current State of Industry?

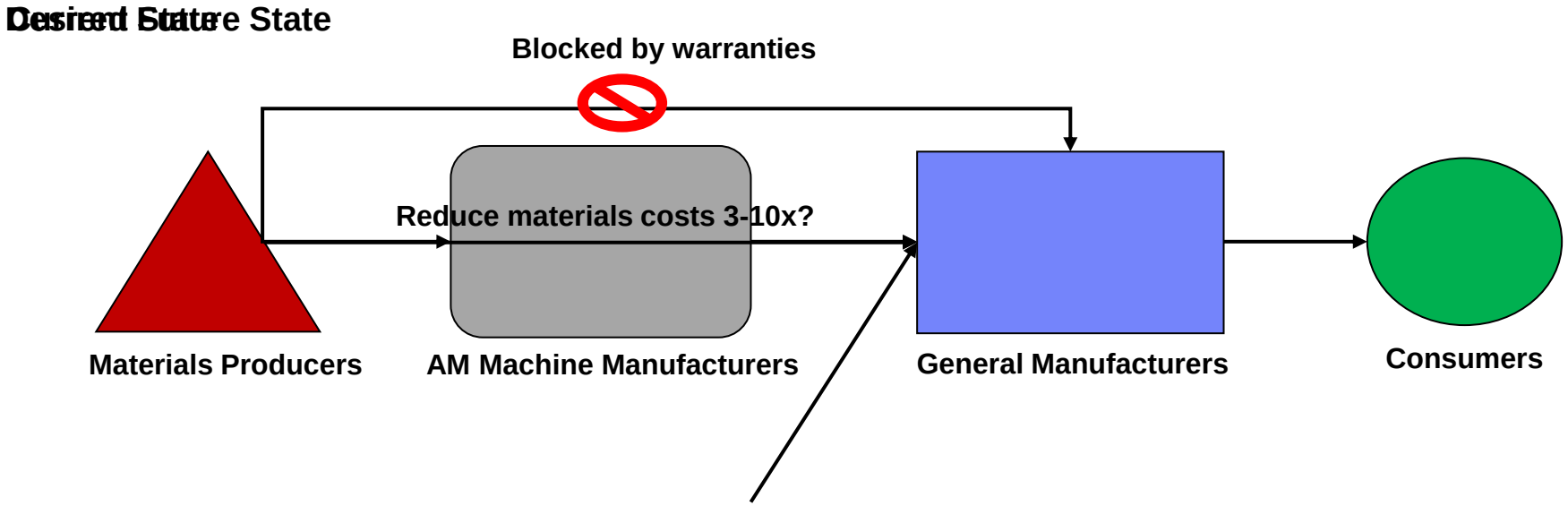


- Key differences between razor blade/HP model and AM:

1) Relative cost to user

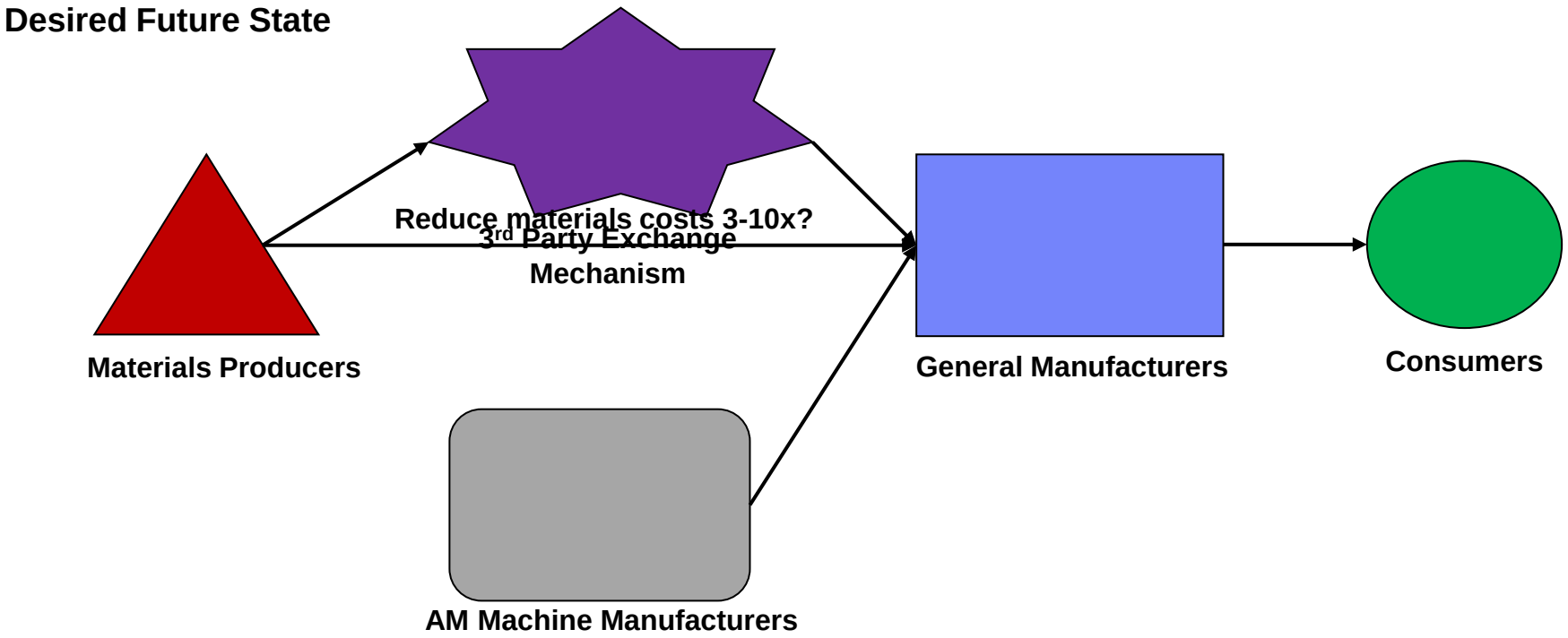
2) Sophistication/willingness to search/innovate of user

To better encourage AM adoption…



- Even this might not be efficient! (each general manufacturer and materials producer would need to develop expensive expertise)

Best Industry Structure?



- A centralized, industry-backed exchange? Initially government-funded, a la NAMII?

Conclusions

Important goals for AM adoption:

1) Materials standardization

2) Increased competition

3) A centralized exchange for buyers and sellers?

Thank you!

Questions?

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Working Paper:
“An Additive Manufacturing Technology Adoption Model”
(with Dr. Terry Harrison)