Innovation Crossover Research

Advanced Manufacturing

Manufacturing process modeling & optimization

Context/Scope

This paper represents research conducted by OVO Innovation for the NSWC Crane Innovation Crossover event October 12-13, 2016. This research is intended to provide more insight into key challenges that were identified within the four technology clusters (Advanced Manufacturing, Cyber/IT, Life Sciences and DoD Technologies) first documented in the Battelle report. OVO consultants interviewed subject matter experts (SMEs) from the private sector, academia and the government identified by NSWC Crane to gather insights into key challenges in each cluster. This report is meant to inform the participants of the Innovation Crossover event and identify new research and new technologies that might address the key challenges.

This research was collected during August and September, 2016. The reports were submitted by OVO to NSWC Crane in late September 2016.

Introductory Narrative

The Innovation Crossover event, scheduled for 12-13 October 2016 in Bloomington is the culmination of months of planning and hard work. Some of this preparatory work involved the initial Battelle study which identified key technology clusters (Advanced Manufacturing, Life Sciences, Cyber/IT and DoD Technologies) in southern Indiana. From these clusters NSWC Crane and its contractor OVO Innovation conducted further, more detailed research, to examine detailed challenges and opportunities in each technology cluster. The reports attached document the research OVO conducted with subject matter experts identified by NSWC Crane in academia, industry and in the government. The reports are meant to document specific challenges within each technology cluster that could become areas of joint research and cooperation across the three constituents in southern Indiana. The reports are provided to you to help you prepare for your participation in the upcoming Innovation Crossover event and to frame both the challenges and active research underway to address these challenges.

Problem Statement

Advanced Manufacturing – Modeling and optimization of advanced hybrid manufacturing processes (build times).

Total life cycle (sustainable manufacturing) based modeling and simulation tools to evaluate manufacturability, sustainability, maintainability, reparability, reusability, and recyclability.

This modeling and optimization process will help prioritize which products are most effective to build based on total life cycle costs.

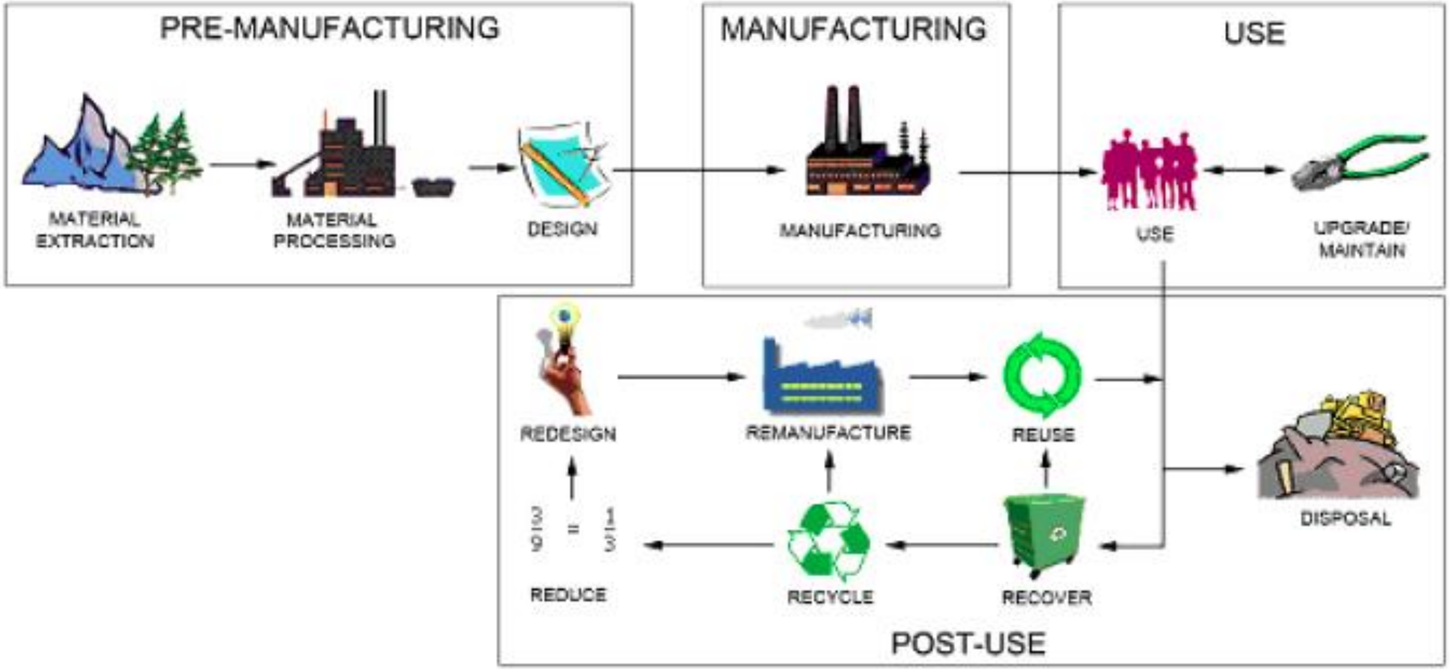
Scope

- Focus of this research was related to total life cycle / sustainable manufacturing.   MBSE & Digital Manufacturing was explored as an enabling effort to support the modeling & optimization

- What is not included:
  - Detailed analysis of the problems related to MBSE or Digital Manufacturing
  - Review of specific software packages or predicative models

Problem Context

Historically, organizations have viewed manufacturing in a siloed approach.   Products and processes should be evaluated in the context of the overall life cycle – pre-manufacturing, manufacturing, use, and post use.



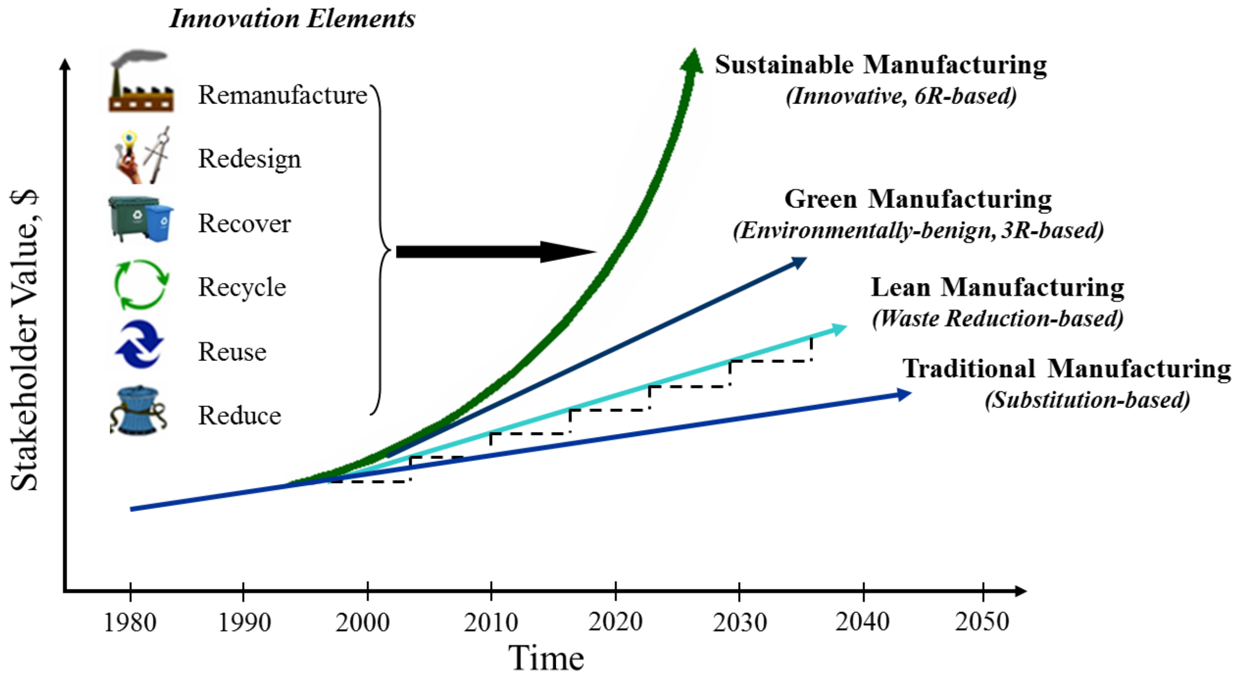
Source: Jawahir, Dillon, et al 2006

Problem Context

Sustainable manufacturing is a continuation of a trend that started much earlier:

- 1 R (Reduce – Lean Mfg in the 80s) ➔ 3 Rs (Reduce, Reuse, Recycle – Green Mfg of the 90s) ➔ Current pursuit of 6 Rs of Sustainable Manufacturing (Reduce, Reuse, Recycle, Recover, Redesign, Remanufacture)

As a more holistic view of the process is included – the result is increased stakeholder value.



Source: Jawahir and Dillon (2007)

Problem Context

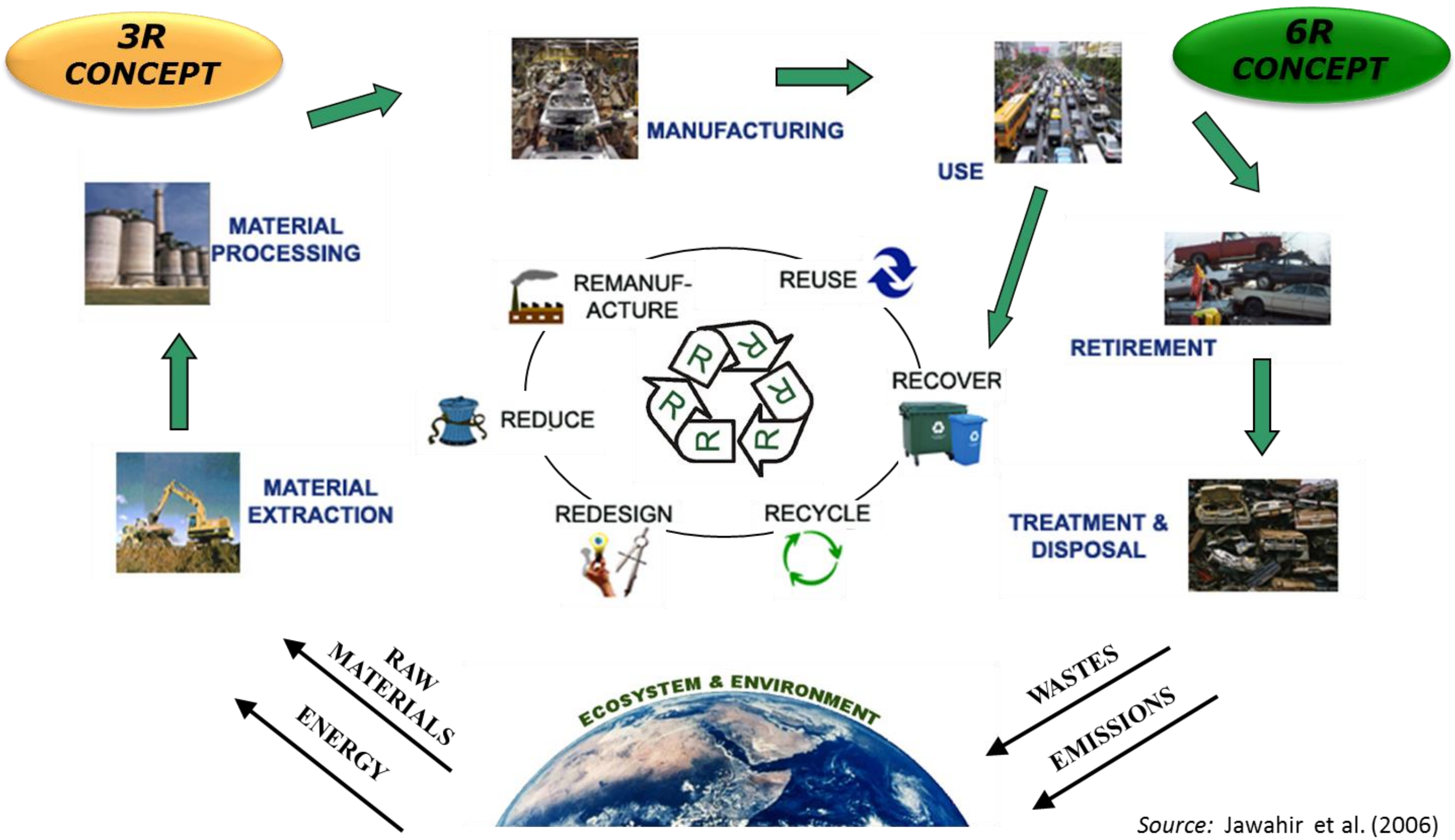
The “6R” concept into a product’s life cycle is aimed at reaching the condition of a perpetual material flow, resulting in a minimization of that product’s ecological footprint.

- **Reduce** involves activities that seek to simplify the current design of a given product to facilitate future post-use activities. Of all the end-of-life activities in the post-use stage,
- **Reuse** may potentially be the stage incurring the lowest environmental impact mainly because it usually involves comparatively fewer processes.
- **Recycle** refers to activities that include shredding, smelting, and separating.
- **Recover** represents the activity of collecting end-of-life products for subsequent post-use activities. It also refers to the disassembly and dismantling of specific components from a product at the end of its useful life.
- **Redesign** works in close conjunction with Reduce in that it involves redesigning the product in view of simplifying future post-use processes.
- **Remanufacture** is similar to manufacturing. However, the difference is that it is not conducted on the virgin material but on an already used product.

Source: Jawahir, Dillon, et al 2006

Problem Context

Sustainability in manufacturing requires a holistic view spanning not just the product and the manufacturing processes involved in its fabrication, but also the entire supply chain, including the manufacturing systems across multiple product life cycles.



Source: Jawahir et al. (2006)

Problem Context

A total life cycle view requires improved models, metrics for sustainability evaluation, and optimization techniques at the product, process, and system levels. MBSE (Model-Based Systems Engineering) and the digital factory are key enablers of this.

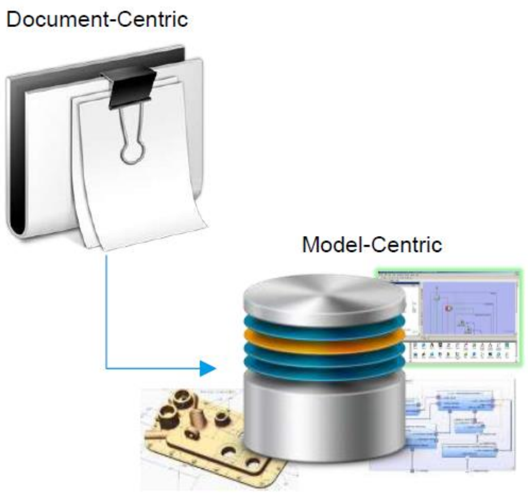
Digital Manufacturing and Design: By capturing data at every stage of the production process—and by deploying specially-designed software and other digital tools—manufacturers can efficiently share and revise their digital designs.

Digital twins: Virtualize a digital representation of any piece of real equipment to enable ability to create, test and build our equipment in a virtual environment. When meeting criteria – would physically manufacture it. Digital "triplet" is similar, but requires virtualizing products that have been returned from the field so it can be simulated to better model maintenance requirements, failures and use.

Siemens

Model-Based Systems Engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.

Relevance of Additive Manufacturing



Digital models have been common in engineering since the late 1960s, but today's focus on Model-Based Systems Engineering goes beyond the use of disparate models.

Model-Based Systems Engineering moves the record of authority from documents to digital models including M-CAD, ECAD, SysML, and UML managed in a data rich environment.

Shifting to model-based enables engineering teams to more readily understand design change impacts, communicate design intent, and analyze a system design before it is built.

Problem Context

Challenges related to adopting a more comprehensive view of manufacturing are complicated by several factors:

- The perceived cost of a total life cycle system can challenge the adoption
- Economic models on benefits of this view are continuing to evolve
- Cultural changes are required within an organization to begin having a longer term view of the benefit

The modeling required to digitize the process and simulate for optimization (MBSE and Digital Manufacturing) also has challenges:

- The costs for implementing these systems can be prohibitive (software, manpower, training, supplier coordination, etc.) for smaller and mid-size companies
- Fear of loss of Intellectual Property as details around the full manufacturing process have to be released by suppliers
- Multiple software vendors each pursuing slightly varied approaches

Problem Relevance

Benefits of sustainable manufacturing include:

- Reduction of manufacturing costs
- Reduction of product development time
- Reduction of material use
- Reduction of energy consumption
- Increased operational safety
- Enhanced societal benefits
- Reduction of industrial waste
- Repair, reuse, recovery, and recycling of used products/materials
- Consideration of environmental concerns
- Education and training of workforce
- Increased product and process innovation

Within certain parts of an aircraft engine, repaired and remanufactured components have shown a cost effectiveness of 16x vs. replacing the entire part, combined with increased safety and longevity.

Source: Jawahir, Dillon 2006

Problem Relevance

The rise of sustainable manufacturing and responsible consumption is spurred by legislation of various governments (European take-back initiatives) and global agencies as well as independent initiatives of large manufacturers. These initiatives will find increasing importance in the years to come. The result will be an increased burden on manufacturing to manage reverse logistics around recycle and reuse.

http://en.volkswagen.com/en/company/responsibility/recycling/take_back.html

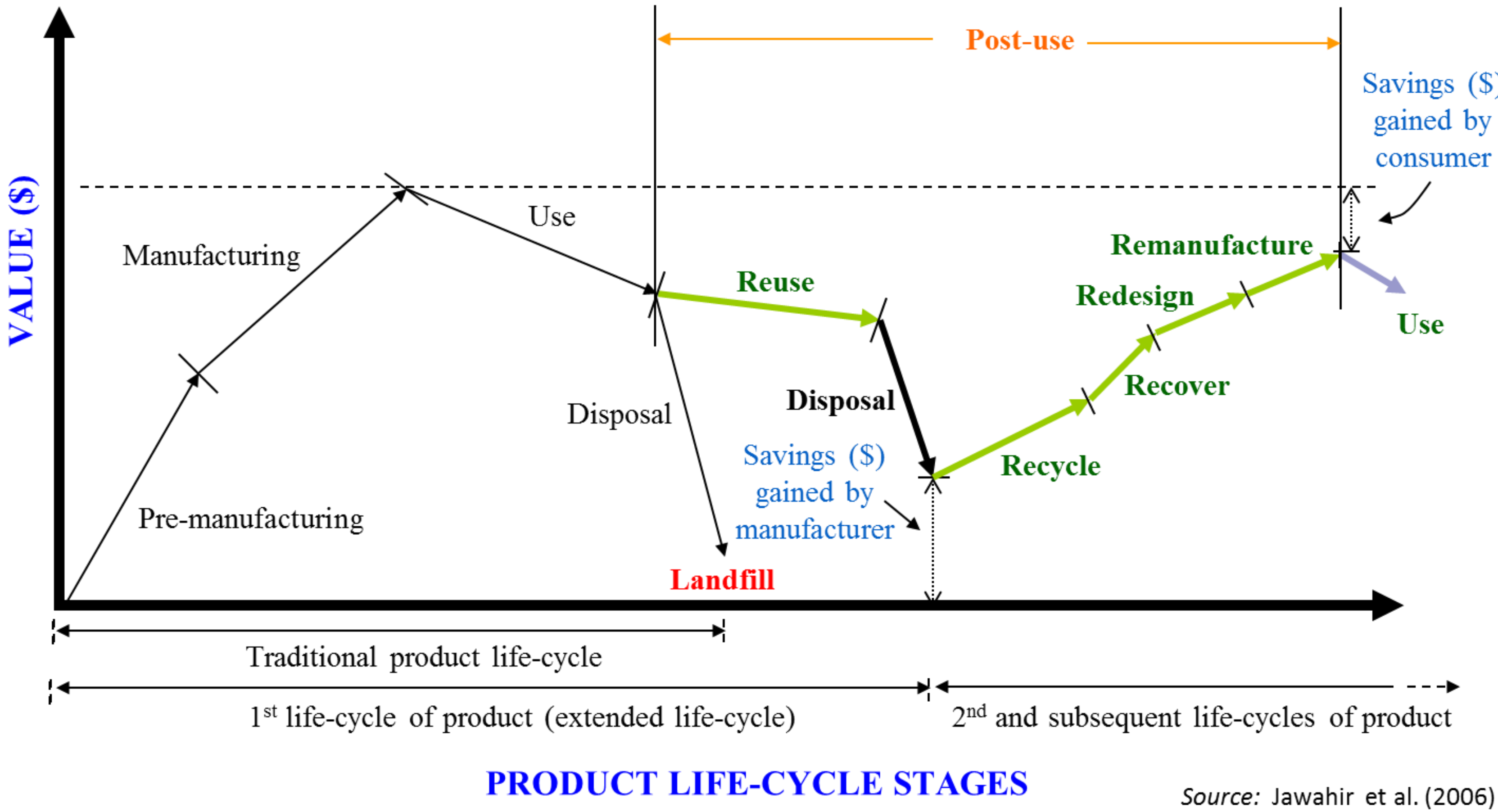
European Directive on End-of-Life Vehicles

With the End-of-Life Vehicles Directive (2000/53/EC) of 18 September 2000, the basis was established for uniform, Europe-wide conditions for the take-back and recovery of end-of-life vehicles. The key points of the Directive include the following:

1. Establishment of systems for the take-back, treatment, and recovery of end-of-life vehicles. The systems must be offered universally (i.e., the take-back facilities must be accessible to the vehicle owner within a reasonable distance).
2. Introduction of a certificate of destruction (COD) to ensure that end-of-life vehicles are taken to the authorized treatment facilities (ATF).
3. Free return option for end-of-life vehicles, provided that no essential components are missing.
4. Regulations for the treatment of end-of-life vehicles to achieve recovery and recycling at a high ecological level. 95% of the vehicle weight must be reused or recovered since January 2015.
5. Hazardous substances must be reduced as far as possible during the development of vehicles in order to prevent hazardous waste. Special limits and bans apply to the heavy metals lead, cadmium, mercury, and chromium (VI).
6. The recoverability of 95% of the vehicle weight has to be proved before the start of series production.

Problem Relevance

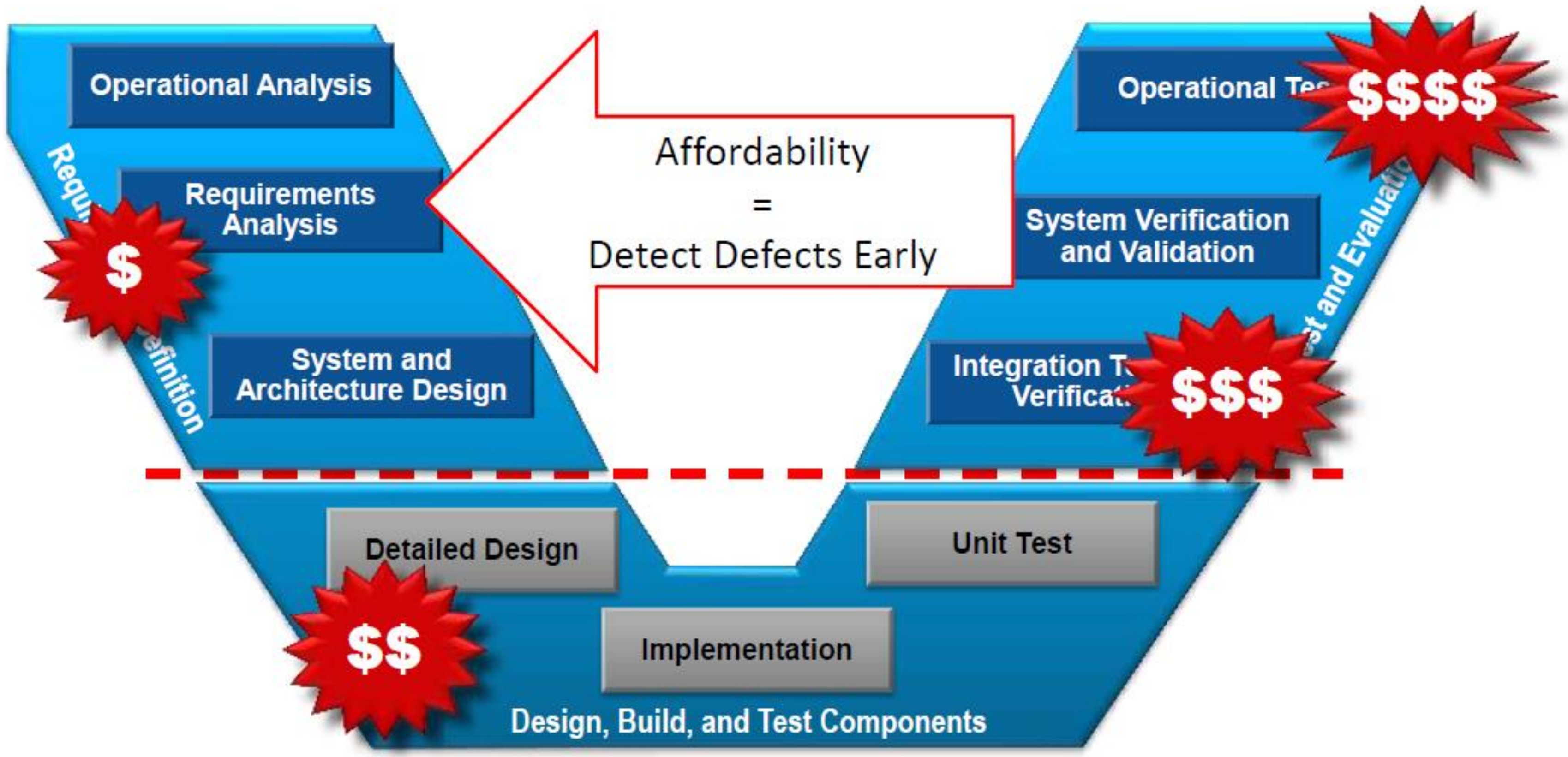
Products no longer reach end-of-life but rather become inputs for future use and new services arise to mitigate the impacts of a throwaway culture. The result is value for both the manufacturer and the consumer.



Source: Jawahir et al. (2006)

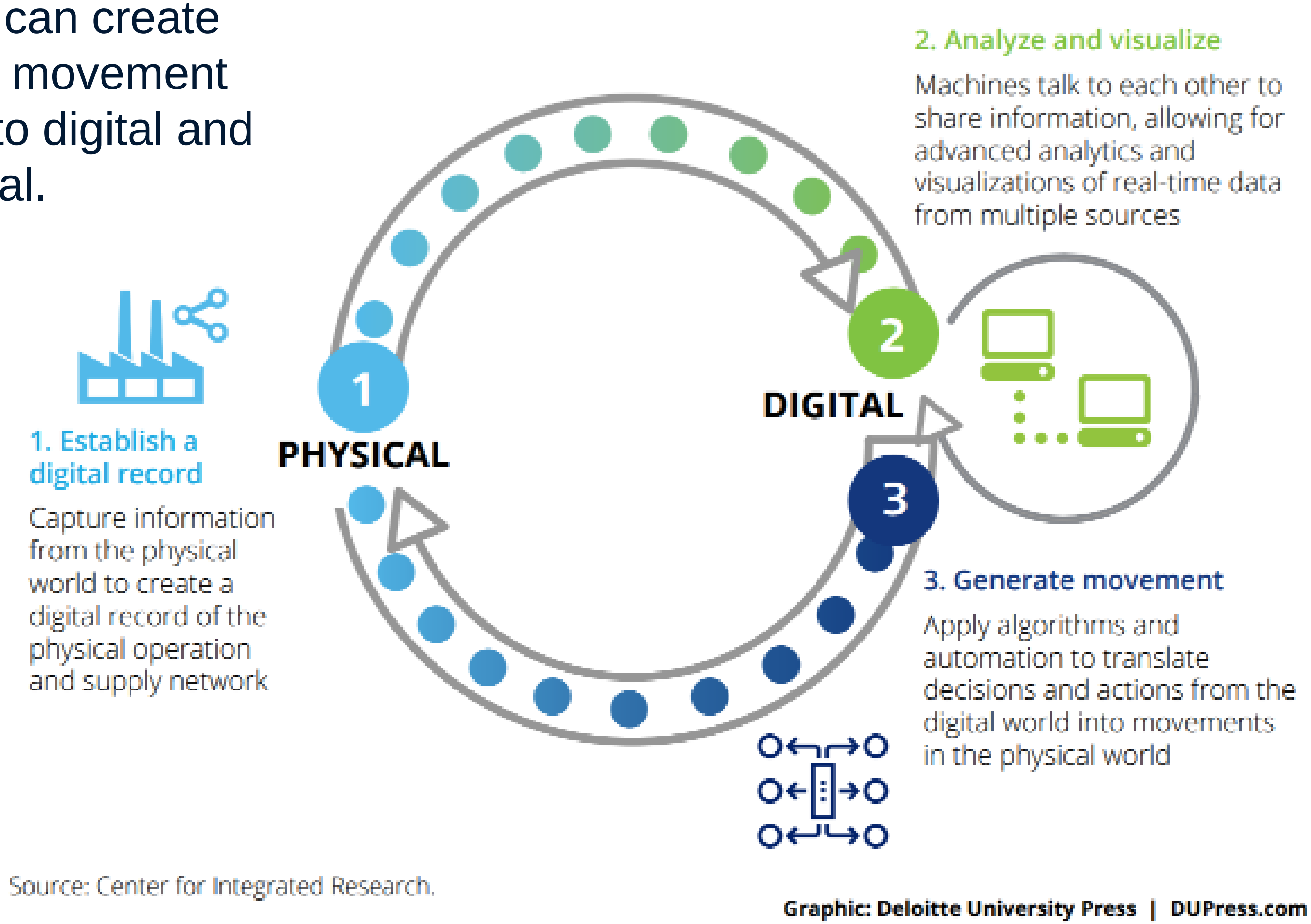
Problem Relevance

With improved modeling and simulation from digital manufacturing and MBSE – it enables earlier detection of defects – which impacts the manufacturing process and total life cycle economics.



Problem Relevance

Organizations can create value from the movement from physical to digital and back to physical.



Source: Center for Integrated Research, Graphic - Deloitte University Press

Problem Relevance

Benefits of Model-Based Systems Engineering

Improved System and Software

- Specification
- Visualization
- Architecture
- Construction
- Simulation and Test
- Documentation

Reduced time to market

- Shorter innovation cycles
- More sophisticated products
- Energy & resource efficiency

Improved Design Quality & Flexibility

- Decreased ambiguity
- Increased precision
- Supports evaluation of consistency, correctness, and completeness
- Supports evaluation of trade space

Supply Chain Optimization

- Predictive asset management
- Process management & control
- Production simulation
- Demand forecasting
- Smart manufacturing

Improved Communications

- Enhanced knowledge capture and transfer
- Training Support

Sample of Research

- **University of Kentucky** – Dr. Jawahir, Sustainable Manufacturing
- **Purdue** – Manufacturing Energy Efficiency and Sustainability Partnerships
- **University of Southern Indiana** – Advanced manufacturing degree program
- **University of Louisville** – Degree program in digital manufacturing
- **Indiana University** – Digital lab for manufacturing
- **Georgia Tech** – Model-Based Systems Engineering Center
- **Rochester Institute of Technology** – Golisano Institute for Sustainability, Center of Excellence in Sustainable Manufacturing
- **University of California, Berkley** – Sustainable Manufacturing Partnership Consortium
- **University of Maryland** – MBSE Colloquia Series
- **MIT** – Architecture and Systems Engineering

Sample of Organizations

- **Institute for Sustainable Manufacturing:** The Institute for Sustainable Manufacturing (ISM) is a multidisciplinary, collaborative unit whose primary objectives are to develop and advance sustainable manufacturing principles and practices in Kentucky, the nation, and the world.

- **National Institute of Standards and Technologies (NIST):** Mapping important environmental aspects of manufacturing process.

- **International Council on Systems Engineering (INCOSE):** INCOSE champions the art, science, discipline, and practice of systems engineering.

- **DDMII**: The Digital Manufacturing and Design Innovation Institute, a federally-funded research and development organization of UI LABS, encourages factories across America to deploy digital manufacturing and design technologies, so those factories can become more efficient and cost-competitive.

- **US Dept of Commerce:** Facilitates sustainability forum annually and also manages Commerce's Sustainable Business Clearinghouse which includes about 800 federal, state, and non-governmental resources. These resources include: case studies, compliance assistance, financial assistance, general information, how-to guides, metrics/assessment tools, research, tax incentives, technical assistance, training opportunities, and voluntary or partnership programs.

Summary

- Industry is beginning to embrace the idea of a circular economy According to a report by the World Economic Forum, a shift towards the circular economy by 2025 could generate an estimated $1 trillion annually in economic value globally, create more than 100,000 new jobs, and prevent 100 million tons of waste within the next five years. It would also restore the natural capital and ecosystem services that are the foundation of healthy societies and economies globally.

- Multiple factors are creating a convergence around sustainable manufacturing – resources are declining, regulations are increasing, consumers prefer environmentally-oriented products, etc. Improvements must provide a return – both at the specific use case and at the larger levels of environment, economy, and society.

- US Chamber of Commerce
- Jayal, Badurdeen, Dillon, Jawahir (2010)

Summary

- Any approach must factor in the product, process, and system. The approach has evolved from the original 3R approach (reduce, reuse, recycle) to a more comprehensive view of 6R (reduce, reuse, recover, redesign, remanufacture, recycle). The impact is a transformation of the overall manufacturing process to a closed loop, total life cycle model.

- To accomplish this, it is essential to consider all aspects of the entire supply chain, taking into account all the major life cycle stages – pre-manufacturing, manufacturing, use, and post-use – over multiple life cycles.

- Adoption of this framework is complicated by perceptions that it is costly, products are less effective, and that it will disrupt the traditional approach to manufacturing. However, developing a clear view about the ability to reduce waste, resources, etc. as part of the secondary life cycle can offset the concerns around cost.

Summary

- To enable the modeling and optimization for this type of effort, MBSE and digital manufacturing will be key enablers. Document-driven approaches have limits due to multiple stakeholders, difficulty maintaining versions, etc. Additionally, as those with the greatest knowledge leave the workforce – the knowledge leaves as well. MBSE allows a replacement of that approach and a more full integration into a digitization of the engineering process. The benefit of MBSE is that it provides a data-centric model that allows for integrated modeling at levels that were not available before.

- In addition to the cost for developing more sophisticated modeling and digital platforms, there is also concern about the burden on suppliers and the opening of ‘black boxes’ for intellectual property required to include in the models.

Summary

As we continue to evolve to a more life cycle-based approach, several factors must be addressed:

- Communicating the value of these approaches to not only the larger OEMs, but also the smaller and midsize manufacturers.
- Quantifying the return that will offset the investment and disruption costs.
- Addressing cultural changes that will be required as new approaches are used for manufacturing, knowledge management, etc.
- Standardization among multiple software packages related to MBSE to enable communication across wide platforms – especially within larger OEMs or government.
- Reducing concern about proprietary data from suppliers being shared as part of the overall digitization of the manufacturing effort. The process requires a much higher level of transparency – which raises significant IP concerns.

Sources

Subject Matter Experts Consulted / Interviewed:

Additive

- Eric St. Ours, NSWC Crane
- Dr. Thomas Starr, University of Louisville
- Dr. Mary Kinsella, ARFL/RXMS
- Chris Sensenbrenner, Flanders
- Chris Brack, George Koch Sons

Manufacturing Process Modeling & Optimization

- Rachel Wiseman, NSWC Crane
- Jacob Chapman, NSWC Crane
- Dan Hartman, Rolls-Royce, DDMII
- Dr. Marlon Pierce, Indiana University
- Dr. I.S. Jawahir, University of Kentucky