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Enabling circular economy through product stewardship

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Abstract

Sustainable manufacturing extends beyond the manufacturing process and the product, to include the supply chain, across multiple product life-cycles as well as end-of-life considerations. Companies can gain a competitive advantage by applying sustainability manufacturing for environmental friendlier products and operations. Industry 4.0 sets new requirements for becoming a sustainable manufacturer where data management, the Internet of Things and extended product service systems are tightly linked with traditional manufacturing processes. Automobile, aircraft and ship manufacturers have either been regulated or have voluntarily adopted product stewardship initiatives to support high quality, end-of-life management. This paper analyses how different 'product stewardship' and 'end-of-life' strategies can support the circular economy and what the challenges and benefits are from an original equipment manufacturer perspective.

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Keywords: Circular Economy; Product Stewardship, Life Cycle Management; Sustainability; End-of-Life Management

1. Introduction

Mårtensson and Westerberg (2016) note that sustainable development and environmental issues have gained attention in the public as well as in companies. A wide range of companies has adopted sustainability agendas to contribute to sustainable development and to manage their relationship with nature. [1] Research indicates that companies tend to apply strategies that do not challenge the concept of business as usual, which in the long run does

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not change companies' relationship with nature. [2] Haigh and Griffiths (2009) notify that a sustainable strategy signifies a company's relationship to nature is integrated and managed throughout the value chain, where information and control systems that support life-cycle thinking are central components of the strategy. [3] However, companies are often motivated by legislative or competitive factors rather than by integrated sustainability values. [4] This also means that environmental information is not systemically managed throughout a company's value chain.

A central concern in the transition towards a sustainability management in companies is resource efficiency. The demand for materials has quadrupled in the past 50 years [5] and further, Graedel et al, 2011 claim that the major deposits have already been explored. Resource scarcity and the impacts of virgin materials are two drivers for improving the resource efficiency [6], which is also noted by the European Union (EU) which highlights resource efficiency as one of its seven flagship initiatives in the 'Europe 2020' strategy. [7]

In recent years, the concept of Circular Economy (CE) has gained attention as a way to overcome issues related continuous growth and resource throughput. The concept aims to increase the resource efficiency by integrating business models and sustainable manufacturing systems that support closing the material loops within an economic system. [8] Elements of CE originate from the work of Boulding (1966), where the idea of an economy as a circular system was considered necessary in order to maintain a sustainable human life on earth. [9] Later Pearce and Turner (1989) introduced a theoretical framework, where they explained the shift from an open economic system to a circular economic system. [10] CE can also be linked to the concept of industrial ecology that promotes the transition from open loop to closed loop material cycles, the use of renewable energy and that leads to less wasteful, and thereby more resource efficient processes. [11-14]

In order to realize the potentials of CE, and especially the power of the 'inner circles', business models for sustainable development are needed, where economic, environmental, technological and social aspects are co-integrated. [15] CE is related to the principles of 'Reduction, Lifetime extension (via service/maintenance), Reuse, Remanufacture and Recycle' [16] and also linked to the waste hierarchy presented by the European Commission. [17] There are well-documented environmental benefits associated with both reuse (product and component level) and recycling (material level) as embodied resources and energy are saved compared to the use of primary resources. This paper explores the product stewardship concept and analyses potential means for enabling a CE strategy from a manufacturer's perspective.

2. Product stewardship

In sustainable manufacturing, the manufacturer extends their work beyond their own processes and products as well as broaden their focus from economic benefits to environmental and social aspects. [18] Sustainable manufacturing includes many aspects of sustainability such as modelling and optimization [19], remanufacturing [20], sustainable supply chains [21], reverse logistics and closed loop supply chains. [22].

Rosen et al (2012) argue that future manufacturing systems are likely to be based on strategies that facilitate sustainable development, so that the environmental quality of future generations goes hand-in-hand with business development. [23] This means extending the traditional focus on manufacturing processes inside the factory towards life-cycle management, which involves preparing for the reuse, remanufacturing, recycling or final safe disposal already at the manufacturing phase. Lane & Watson (2012) argue that recycling and product stewardship are rapidly expanding areas that have an increasingly important role for conserving resources in the manufacturing sector. [24]

The term 'Product Stewardship (PS)' is interpreted differently, but often interlinked with the concept of Extended Producer Responsibility (EPR). Lewis (2005) finds that 'stewardship' related to environmental management was first mentioned by the Canadian Chemical Producers Association in the late 1970s [25], but re-emerged in the 1990s in relation to material responsibility. [26-28]

The concept of PS evolved from responsible management of hazardous wastes towards a broader focus on resource conservation. PS approaches have changed the relationship between the societal and material worlds [29] and new industrial sectors have arisen from these initiatives and resulted in the formation of partnerships. [30]

PS agreements have either been driven by government or industry, and have involved some form of collaboration between these two actors. The PS agreements can be divided into (1) fully regulated, (2) co-regulated or (3) fully voluntary agreements. [24]

The ultimate goal of engaging in PS is to minimize the environmental impacts of the products through the life cycle(s). [31] In the following section, PS arrangements for the automobile, aircraft and shipping industry are presented.

3. Product stewardship in practice

3.1. Automotive industry

In 2010, the International Organization of Motor Vehicle Manufacturers estimated that one billion automobiles were in circulation worldwide, which makes the automotive industry one of the largest consumers of metals. [32] Material selection for the approximately 10,000 parts that make up a car has a great impact on the reuse or recycling potentials, and the trend is that metals are substituted with composite materials. [33] The average lifetime for automobiles is 10-12 years in the EU and in 2010, 40.2 million and 7.8 million automobiles reached their end-of-life globally and in the EU respectively, which corresponds to 5% of the World's industrial waste. [34-35]

ELV gained political focus in the early 1990's, which helped establish a market for recycling and reusing parts and components, which fostered new suppliers, dismantlers and automobile recycling factories. [34] Development in the complexity of parts and materials have made high-value recycling more difficult and from a waste management point of view, the concerns related to ELVs are twofold: (1) Approximately 25% of the waste is considered hazardous, (2) Challenges exist in retaining high value materials from the product by separating different alloy metals. [34]

3.1.1. *The end-of-life vehicle directive*

The European Commission officially adopted the ELV Directive in 2000, which now regulates the automotive industry to make dismantling and recycling environmental friendly. [36] It has since been continuously improved to clarify legal aspects, national practices and recommendations. Several manufacturers have collaborated on the development of the 'Internal Dismantling Information System' (IDIS) – a shared software platform to meet the legal obligations of the directive. [37] The IDIS database was created to assist in dismantling of parts in the quickest and least complicated way – and thereby most economical. One of the key features is the identification of economically recyclable plastic parts as all plastic parts exceeding 100 grams are coded to ensure systematic recycling. This has fostered innovations in the automotive industry that support 'closed-loop-recycling', where some materials go back into the automobiles as secondary raw material [38] and helped to: (1) Prevent use hazardous materials (reduction of 96-99,99%), (2) Code and/or inform on parts and components, (3) Ensure information for consumers and treatment organizations (achieved, but criticized for being too bureaucratic and costly) and (4) Achieve reuse, recycling and recovery performance targets **(**significantly improved and increased willingness to integrate recycled materials in design). [37]

3.2. Ship industry

An increased demand for commercial transport has resulted in an increase in the numbers and size of ships. [39-40] Ships have a service life of 20 to 30 years, after which they are usually sold and dismantled to recover steel and other valuable parts. [41-42] The valuation of a ship as it ages is complex but the European Commission states that '*freight rates determine* ***when*** *to scrap; labour costs determine* ***where*** *to scrap; steel prices determine the size of the ship owner's* ***profit***'. [43]

Dismantling of ships was common in southern Europe and USA in the 1940s to 1960s, but have moved now to countries like India, Bangladesh and Pakistan. Scrapping ships has drawn public and political attention as it leaves large environmental footprints if handled in non-controlled ways. [41-44]

Ships can contain large amounts of toxic and hazardous substances, which can cause adverse effects on the natural environment and humans. However, up to 95% of the ships (mainly steel, aluminum and copper) are reused or recycled Ships manufactured in the 1980s contain materials that are restricted and banned today, i.e. asbestos and heavy metals. [41] The disposal of hazardous waste is regulated under the existing 1989 Basel Convention. [42]

3.2.1. *The Hong Kong Convention*

Ship breaking has throughout the years gained more public and political attention. Picked up in the 1990s by IMO a through a series of industry codes, the Hong Kong Convention (HKC) was adopted in 2009 [41, 44] including an inventory of hazardous materials [IHM] that should enable a 'cradle-to-grave' approach for ship recycling, with focus on avoiding hazardous materials in new ships. [43] The IHM is central in the HKC as a document containing an inventory of the materials used in ship manufacturing, including materials that are potentially hazardous to humans or the environment. The IHM accompanies the ship throughout its service life and changes are recorded. The final owner is expected to deliver the IHM with the ship to the recycler and virtually all materials can be recycled or utilized locally. [44-45] In 2013, the European Ship Recycling Regulation also entered into force in 2013, which also emphasizes documentation of materials and especially hazardous materials on-board. The regulation applies to all ships of 500 GT and above, which includes 55.000 existing ships and all new ships. [46]

3.2.2. *Maersk's Cradle2Cradle Passport*

Maersk Line, has been working on a 'cradle2cradle' (C2C) passport for their Triple-E fleet. The aim of the passport is to create a document that marks the materials into different material categories as well location of all materials in addition to dismantling and recycling instructions. The expectation is that the salvage value can increase up to 10 % due to the increased knowledge of the ship. [47-48]

To support this, Maersk has adopted the CDX system for material registration. The tool was developed for the automotive industry and then re-developed for the shipping industry, where an industry-wide standard has been proposed. However, collaborating across the value chain has proven difficult. [49]

3.3. Aircraft industry

A new aircraft has an estimated design life of 20 to 30 years, after which is historically either store or demolished and recycled. [50] A significant number of aircraft is stored in aircraft graveyards, which can be an expensive strategy considering lost revenue from salvage values and use of land. [51-52] However, the actual service-life is declining with planes as young as 15 years or less are being scrapped. [53-54] Formerly, aging planes were defined by calendar years and operating hours but today, sophisticated models analyse the relative value of an aircraft to determine service life. [55] Estimations state that between 8,500-12,500 planes will be at end-of-service life within the next 20 years. [50-56]

Recently, the end-of-service life for aging planes and related parts became a key subject in recycling industries worldwide. The absence of relevant directives, size of treated materials from end-of-life products, complexity in fleet recycling process, multi-layered relationship among partners and players are highlighted as some of the challenges facing the aircraft industry. [53] Different end-of-life strategies is being applied, but since 2005, the projects 'Process for Advanced Management of End-of-Life of Aircraft (PAMELA) and Aircraft Fleet Recycling Association (AFRA) have been carried out to support end-of-service-life handling [59]

3.3.1. *PAMELA*

The first major study on aircraft recycling was initiated by Airbus in 2005. PAMELA was a dismantling demonstration project carried out with support from several partners and the European Commission. The objectives of PAMELA were to: 1) demonstrate full-scale experimentation on aircraft where 85% could be recycled, reused or recovered, 2) set up a standard for environmentally responsible management at the end-of-life, and 3) develop an international network of partners to further disseminate this topic. [57] The project demonstrated the possibility of recycling up to 85% of plane components - a significant advance from the earlier rate of 60% and a reduction in landfilled waste. [57] The project showed that a material mapping in the design phase would support high value recycling and would eliminate the need for spectrometric analysis. Further, the complexity in material composition and assembly was highlighted as an obstacle to achieve higher recycling rates. [57]

3.3.2. *AFRA*

In 2006, Boing launched the AFRA initiative with ten other founding members. The aim was to be proactive on recycling of aircraft to hinder the development of a political or legal problem and develop industrial standards that could be the basis for government action. [61] Similar to PAMELA, AFRA has promoted best practice within end-of-life and has developed a series of guidelines on best management practices (BMP). [54] Three versions have been published and merged in one covering all aspects of best practice around aircraft end-of-life processes and service. [52] The final documents aim is to reach 90% recycling by 2016. [62]

Common to the initiatives is that all increase the recycling rates, decrease the landfill needs and have fostered a market for reuse of components. The area is still not regulated and legislative instruments can be used to set the lowest common denominator for ensuring minimum requirements. Despite the achievements, the aircraft industry still has challenges defining responsibilities and determining how to communicate information, e.g. material compositions, etc. [65]

4. Enterprise Information Systems as a support tool for product stewardship

Common to all three industry-examples of PS is that a management information system can help handle the exchange of information along the product life cycle. New technologies have the potential to improve the efficiency of doing business including improved management of products and resources. [66] Digitalization and end-to-end optimization opens new possibilities - from automation of many work steps to decision support in situations like reuse and recycling. It calls for new data streams to be managed and central tools to handle information. Product life cycle management (PLM) software or enterprise information system (EIS) are such information handling tools, where partners share information and collaborate on various issues, e.g. optimization of recycling or reuse of materials. [66] Several authors highlight examples from the ship and automotive industries, e.g. how e-collaboration can support and improve supply chain operations through efficient data exchange as well as estimate dismantling costs and salvage value. [67-70] Digitalization in the form of an EIS is a mean that can potentially support the integration of PLM and such platforms can act as the basis for integrating environmental information on e.g. material composition of products to stimulate high-quality recycling or better reuse of components or products. [71] The principles of circular economy have not traditionally been part of the EIS, but can as shown stimulate PS and increase resource efficiency. The implementation of an EIS to support PS poses challenges e.g. regarding data recording between a large range of stakeholders requires compatibility of definitions, which is a considerable hurdle to overcome. When establishing interfaces and transferring sensitive data between stakeholders issues related to information security and confidentiality are also present. [30]

However, moving from non-automated or a paper based system to a digitalized one is likely to generate new business value to many actors across the value chain. Further, potential benefits of integrating information on material composition in an EIS includes an increased understanding of product (and thereby understanding of business risks), the possibility of making real-time life cycle assessments (as the data collection phase can be automated), and thereby improve both assessment and continuous improvement processes in the product design stage.

5. Conclusion

Sustainable manufacturing extends beyond the manufacturing process and the product, to include the supply chain, across multiple product life-cycles as well as end-of-life considerations. PS as a concept relates to the realm of the circular economy, where the inner circles are promoted and business models for sustainable development are developed. The CE relates to the principles of reduction, lifetime extension (via service/maintenance), reuse, remanufacture and recycle.

Through a number of industry examples (automotive, ship and aircraft industries), this paper has shown different approaches of PS – from fully regulated to fully voluntary – and demonstrated how they can help stimulate a transition to a more circular, resource efficient form of sustainable manufacturing.

Further, integration of environmental information into the EIS such as PLM software can digitalize and generate new business value to actors across the value chain. The concept is not yet widely utilised, but an increased understanding of the product and manufacturing processes, improved assessment possibilities (in real time) as well as better improvement possibilities are some of the benefits. However, considerable hurdles have also to be overcome related to compatibility of definitions in the value chain, information security and confidentiality, when establishing interfaces and sharing sensitive data between stakeholders.

References

[1] K. Mårtensson and K. Westerberg, "Corporate Environmental Strategies Towards Sustainable Development," *Business Strategy and the Environment,* vol. 25, pp. 1-9, 2016.

[2] D. Springett, "Business conceptions of sustainable development: a perspective from critical theory," *Business Strategy and the Environment,* vol. 16, pp. 339-353, 2003.

[3] N. Haigh and A. Griffiths, "The natural environment as a primary stakeholder: the case of climate change," *Business Strategy and the Environment,* vol. 18, pp. 347-359, 2009.

[4] A. Paulraj, "Environmental motivations: a classification scheme and its impact on environmental strategies and practices," *Business strategy and the Environment,* vol. 18, pp. 453-468, 2009.

[5] J. M. Allwood, M. F. Ashby, T. G. Gutowski and E. Worrell, "Material efficiency: A white paper," *Resources, Conservation and Recycling,* no. 55, pp. 362-381, 2011.

[6] T. Graedel, J. Allwood, J. Birat, B. Reck, S. Sibley, S. G., M. Buchert and C. Hagelücken, "Recycling Rates of Metals - A Status Report, A Report of the Working Group on Global Metal Flows to the International Resource Panel," UNEP, 2011.

[7] European Commission, "The Roadmap to a Resource Efficient Europe," European Commission, Brussels, 2011.

[8] P. Ghisellini, C. Cialani and S. Ulgiati, "A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems," *Journal of Cleaner Production,* pp. 1-22, 2015.

[9] K. Boulding, "The economy of the coming spaceship earth," *Economics, Ecology, Ethics,* 1966.

[10] D. Pearce and R. Turner, "Economics of Natural Resources and the Environment".

[11] R. Frosch and N. Gallopoulos, "Strategies for Manufacturing," *Scientific American,* vol. 261, no. 3, pp. 94-102, 1989.

[12] J. Ehrenfeld and N. Gertler, "Industrial Ecology in practice. The evolution of interdependence at Kalundborg," *Journal of Industrial Ecology,* vol. 1, no. 1, pp. 67-79, 1997.

[13] S. Erkman, "Industrial Ecology: a historical view," *Journal of Cleaner Production,* vol. 5, no. 1, pp. 1-10, 1997.

[14] M. Andersen, "An introductory note on the environmental economics of the circular economy," *Sustainability Science,* vol. 2, pp. 133-140, 2007.

[15] J. Mathews and H. Tan, "Progress towards a circular economy: the drivers and inhibitors of eco-industrial initiative," *Journal of Industrial Ecology,* vol. 15, pp. 435-457, 2011.

[16] B. Su, A. Heshmati, Y. Geng and X. Yu, "A review of the circular economy in China: moving from rethoric to implementation," *Journal of Cleaner Production,* vol. 42, 2013.

[17] European Commission, "Directive 2008/98/EC on waste (Waste Framework Directive)," European Commission, Brussels, 2008.

[18] C. B. Joung, J. Carrell, P. Sarkar and S. C. Feng, "Categorization of indicators for sustainable manufacturing," *Ecological Indicators,* vol. 24, pp. 148-157, 2012.

[19] A. Jayal, F. Badurdeen, O. Dillon and I. Jawahir, "Sustainable manufacturing: Modelling an optimization challenges at the product, process and system levels," *CIRP Journal of Manufacturing Science and Technology,* vol. 2, pp. 144-152, 2010.

[20] N. Nasr, B. Hilton and R. German, "A framework for sustainable production and a strategic approach to a key enabler: remanufacturing," *Advances in Sustainable Manufacturing,* vol. 5, pp. 191-196, 2011.

[21] M. Shuaib, H. Metta, T. Lu, F. Badurdeen, I. Jawahir and T. Goldsby, "Design and performance evaluation of

sustainable supply chains: Approach and methodologies," *Advances in Sustainable Manufacturing,* vol. 8, pp. 347-352, 2011.

[22] M. Jaber, A. El Saadaany and M. Rosen, "A simple price-driven reverse logistics system with entropy and exergy costs," *International Journal of Exergy,* vol. 9, pp. 486-502, 2011.

[23] M. A. Rosen and H. A. Kishawy, "Sustainable Manufacturing and Design: Concepts, Practices and Needs," *Sustainability,* vol. 4, pp. 154-174, 2012.

[24] R. Lane and M. Watson, "Stewardship of things: The radical potential of product stewardship for re-framing responsibilities and relationships to products and materials," *Geoforum,* vol. 43, pp. 1254-1265, 2012.

[25] H. Lewis, "Defining product stweardship and sustainability in the Australian packaging industry," *Environmental Science and Policy,* vol. 8, pp. 45-55, 2005.

[26] S. Hart, "A natural-resource-based view of the firm," *Academy of Management Review,* vol. 20, pp. 986-1014, 1995.

[27] S. Hart, "Beyond greening: strategies for a sustainable world," *Harvard Business Review,* vol. 20, pp. 66-77, 1997.

[28] P. Michealis, "Product stewardship, waste minimization and economic efficiency: lessons from Germany," *Journal of Environmental Planning and Management,* vol. 38, pp. 231-243, 1995.

[29] G. Bridge, "Material worlds: natural resources, resource geography and the material economy," *Geography Compass,* vol. 3, pp. 1217-1244, 2009.

[30] H. Schroeder, "Trends in Recycling and Product Stewardship: A Case for Enterprise Information Systems," *Sustainability: The Journal of Record,* vol. 6, no. 6, pp. 320-326, 2013.

[31] P. Deutz, "Producer responsibility in a sustainable development context: ecological modernisation or industrial ecology," *Geographical journal,* vol. 175, pp. 274-285, 2009.

[32] H. Ohno, K. Matsubae, K. Nakajima, Y. Kondo, S. Nakamura and T. Nagasaka, “Toward the efficient recycling of alloying elements from end of life vehicle steel scrap,” *Resources, Conservation and Recycling,* vol. 100, pp. 11-20, 2015.

[33] A. Lashlem, D. Wahab, S. Abdullah and C. Che Haron, “A Review on End-of-Life Vehicle Design Process and Management,” *Journal of Applied Sciences,* vol. 13, no. 5, pp. 654-662, 2013.

[34] V. Simic, “End-of-life vehicle recycling - A review of the state-of-the-art,” 2013.

[35] R. Widmer, X. Du, O. Haag, E. Restrepo and P. A. Wäger, “Scarce Metals in Conventional Passenger Vehicles and End-of-Life Vehicle Shredder Output,” *Environmental Science and Technology,* vol. 49, p. 4591−4599, 2015.

[36] Directive 2000/53/EC-a, "On end-of-life vehicles, L269/34," Official Journal of the European Communities, 2000.

[37] European Commission - DG Environment, “Ex-post evaluation of certain waste stream Directives,” European Commission, Brussels, 2014.

[38] BMW Group, “Recycling of end-of-life vehicles,” BMW Group, München, 2004.

[39] S. M. Gupta and A. Pandit, “A stragtegic approach in making end-of-life decisions for ships,” Boston, 2015.

[40] The Shipbuilders' Association of Japan, “Shipbuilding Statistics,” SAJ, 2015.

[41] V. Rossi, “The Dismantling of End-of-Life Ships: The Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships,” 2011.

[42] A. M. Hiremath, S. K. Pandey, D. Kumar and S. R. Asolekar, “Ecological Engineering, Industrial Ecology and Eco-Industrial Networking Aspects of Ship Recycling Sector in India,” Bombay, 2014.

[43] European Commission Directorate General Environment, “Ship Dismantling and Pre-cleaning of Ships: Final report,” European Commission, 2007.

[44] Lloyd's Register Marine, “A Guide to the Inventory of Hazardous Materials (IHM),” Lloyd's Register Marine, 2014.

[45] International Maritime Organization, “Internation Maritime Organization,” n.d. [Online]. Available: http://www.imo.org/en/OurWork/Environment/ShipRecycling/Pages/Default.aspx. [Accessed 03 July 2015].

[46] DNV-GL, “Guide on Smarter, Safer, Greener Maritime Future,” DNV-GL, 2014.

[47] J. Sterling, “Maersk Line’s Triple-E skibe – bæredygtighed i et 30 årigt perspektiv,” Skibsteknisk selskab, 2011.

[48] C2C-Centre, “C2C-Centre,” 2011. [Online]. Available: http://www.c2c-centre.com/library-item/maersk-cradle-cradle%C2%AE-passport. [Accessed 14 September 2015].

[49] M. Stensen, Interviewee, *Maersk and C2C Passport.* [Interview]. 2013.

[50] C. Chandler, “Aircraft Recycling - Going green and growing,” *Turbine Technology,* pp. 18-24, March 2013.

[51] M. Overcash, E. Asmatulu and J. Twomey, “Recycling of Aircraft: State of the Art in 2011,” *Journal of Industrial Engineering,* vol. 2013, pp. 1-8, 2012.

[52] J. Holland, “From cradle to cradle: The aim of the aircraft recycling industry,” *Aircraft Technology - Engineering & Maintenance,* pp. 30 - 33, March 2014.

[53] S. Keivanpour, D. Ait-Kadi and C. Mascle, “Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects,” *Journal of Management and Sustainability,* vol. 3, no. 3, pp. 76-95, 2013.

[54] M. Todd, “Creative developments: End-of-life solutions,” *Airline Fleet Magazine,* pp. 28-31, November-December 2013.

[55] D. Heerden and R. Curran, “Value extraction from end-of-life aircraft,” *Encyclopedia of Aerospace Engineering,* 2010.

[56] H. Canaday, “Scrambling for Parts,” *Aviation Week & Space Technology,* 7 April 2014.

[57] LIFE - European Commission, "PAMELA - Process for Advanced Management of End of Life of Aircraft," Airbus, 2005.

[58] E. Asmatulu, M. Overcash and J. Twomey, “Evaluation of recycling efforts of aircraft companies in Wichita,” *Resources, Conservation and Recycling,* no. 80, pp. 36-45, 2013.

[59] M. Watson, “End of life aircraft initiatives,” SBAC Aviation and Environment, 2009.

[60] J. Perry, “Sky-high potential aircraft recycling,” *Aircraft Maintenance,* pp. 2-5, March 2012.

[61] M. Mecham, “Cleaning Up,” *Aviation Week & Space Technology,* pp. 144-145, 07 July 2006.

[62] M. Mecham, “Return to Sender,” *Aviation Week & Space Technology,* pp. 18-18, 31 December 2012.

[63] J. Atherton, “Declaration by the Metals Industry on Recycling Principles,” *International Journal of Life Cycle Assessment,* vol. 12, no. 1, pp. 59 - 60, 2007.

[64] J. Yi, B. Yu, L. Du and C. H. D. Li, “Research on the selectable disassembly strategy of mechanical parts based on the generalized CAD model,” *International Journal of Advanced Manufacturing Technology,* vol. 37, pp. 599-604, 2008.

[65] S. Keivanpour, “An Integrated approach to Value Chain Analysis of End of Life Aircraft Treatment,” Université Laval, Québec, 2015.

[66] B. Marr, "Why Everyone Must Get Ready For The 4th Industrial Revolution," *Forbes Tech,* 05 April 2016.

[67] S. Makris, D. Mourtzis, N. Papakostas and G. Chryssolouris, "e-Collaboration for Ship repair Supply Chain Management," in *IEEE Conference on Emerging Technologies and Factory Automation*, Catania, 2005.

[68] S. Makris, V. Xanthakis, D. Mourtzis and G. Chryssolouris, "On the information modeling for the electronic operation of supply chains: A maritime case study," *Robotics and Computer-Integrated Manufacturing,* vol. 24, pp. 140-149, 2008.

[69] S. Makris and G. Chryssolouris, "Web-services-based supply-chain-control logic: an automotive case study," *International Journal of Production Research,* vol. 51, no. 7, pp. 2077-2091, 2013.

[70] N. Papakostas, G. Pintzos and C. Triantafyllou, "Computer-aided design assessment of products for end of life separation and material handling," *CIRP Annals - Manufacturing Technology,* vol. 64, pp. 185-188, 2015.

[71] PWC, "Industry 4.0: Building the Digital Enterprise," PWC, 2016.