An Integrated approach to Value Chain Analysis of End of Life Aircraft Treatment

Thèse

Samira Keivanpour

Doctorat en génie mécanique
Philosophiæ Doctor (Ph.D.)

Québec, Canada

Résumé

Dans cette thèse, on propose une approche holistique pour l'analyse, la modélisation et l'optimisation des performances de la chaîne de valeur pour le traitement des avions en fin de vie (FdV). Les recherches réalisées ont débouché sur onze importantes contributions. Dans la première contribution, on traite du contexte, de la complexité, de la diversité et des défis du recyclage d'avions en FdV. La seconde contribution traite du problème de la prédiction du nombre de retraits d'avions et propose une approche intégrée pour l'estimation de ce nombre de retraits. Le troisième et le quatrième articles visent à identifier les parties prenantes, les valeurs perçues par chaque partenaire et indiquent comment cette valeur peut affecter les décisions au stade de la conception. Les considérations relatives à la conception et à la fabrication ont donné lieu à quatre contributions importantes. La cinquième contribution traite des défis et opportunités pouvant résulter de l'application des concepts de la chaîne logistique verte, pour les manufacturiers d'avions. Dans la sixième contribution, un outil d'aide à la décision a été développé pour choisir la stratégie verte qui optimise les performances globales de de toute la chaîne de valeur en tenant compte des priorités et contraintes de chaque partenaire. Dans la septième contribution, un modèle mathématique est proposé pour analyser le choix stratégique des manufacturiers en réponse aux directives en matière de FdV de produits comme le résultat des interactions des compétiteurs dans le marché. La huitième contribution porte sur les travaux réalisés dans le cadre d'un stage chez le constructeur d'avions, Bombardier. Cette dernière traite de l'apport de « l'analyse du cycle de vie » au stade de la conception d'avions. La neuvième contribution introduit une méthodologie d'analyse de la chaîne de valeur dans un contexte de développement durable. Finalement, les dixième et onzième contributions proposent une approche holistique pour le traitement des avions en FdV en intégrant les concepts du « lean », du développement durable et des contraintes et opportunités inhérentes à la mondialisation des affaires. Un modèle d'optimisation intégrant les modèles d'affaires, les stratégies de désassemblage et les structures du réseau qui influencent l'efficacité, la stabilité et l'agilité du réseau de récupération est proposé. Les données requises pour exploiter le modèle sont indiquées dans l'article.

Mots-clés: Fin de vie des avions, analyse de la chaîne de valeurs, développement durable, intervenants.

Abstract

The number of aircrafts at the end of life (EOL) is continuously increasing. Dealing with retired aircrafts considering the environmental, social and economic impacts is becoming an emerging problem in the aviation industry in near future. This thesis seeks to develop a holistic approach in order to analyze the value chain of EOL aircraft treatment in the context of sustainable development. The performed researches have led to eleven main contributions.

In the first contribution, the complexity and diversity of the EOL aircraft recycling including the challenges and problem context are discussed. The second contribution addresses the challenges for estimation of retired aircrafts and proposes an integrated approach for prediction of EOL aircrafts. The third and fourth contributions aim to identify the players involved in EOL recycling context, values perceived by different shareholders and formulate that how such value can affect design decisions. Design stage consideration and manufacture's issues are discussed and have led to four main contributions. The fifth contribution addresses the opportunities and challenges of applying green supply chain for aircraft manufacturers. In the sixth contribution, a decision tool is developed to aid manufactures in early stage of design for their green strategy choices. In the seventh contribution, a mathematical model is developed in order to analyze the strategic choice of manufacturers in response to EOL directives as the result of the interaction of competitors in the market. An internship project has been also performed in Bombardier and led to the eighth contribution, which addresses life cycle approach and incorporating the sustainability in early stage of design of aircraft. The ninth contribution introduces a methodology for analyzing the value chain in the context of sustainable development. Finally, the tenth and eleventh contributions propose a holistic approach to EOL aircraft treatment considering lean principals, sustainable development, and global business environment. An optimization model is developed to support decision making in both strategic and managerial level.

The analytical approaches, decision tools and step by step guidelines proposed in this thesis will aid decision makers to identify appropriate strategies for the EOL aircraft treatment in the sustainable development context.

Keywords: End of life aircraft, value chain analysis, sustainable development, stakeholders,

Table of Content

List of Tables

List of Figures

Glossary of Used Abbreviations

ACI	Airport Council International
AFRA	Aircraft Fleet Recycling Association
AFV	Avion en Fin Vie
ANFIS	Adaptive Neuro Fuzzy Inference System
ANP	Analytic Network Process
ASR	Auto Shredder Residue
ATAG	Air Transport Action Group
CAFE	Corporate Average Fuel Economy
CMO	Current Market Outlook
CRIAQ	Research and Innovation in Aerospace in Quebec
DfD	Design for Disassembly
DfE	Design for Environment
EFQM	European Foundation for Quality Management
ELA	End of Life Aircraft
ELV	End of Life Vehicle
ENI	Environmental Index
ENV	Environment
EOL	End of Life
EOLARP	End Of Life Aircraft Recycling Projects
EPA	US Environmental Protection Agency
EPD	Environmental Product Declarations
ERP	Extended Product Responsibility
ESS	Evolutionary Stable Strategy
EU	European Union
FCM	Fuzzy C-means Clustering
FIS	Fuzzy inference system
GDP	Gross Domestic Product
GMF	Global Market Forecast
GOAT	Global Outlook for Air Transportation
GUI	Graphical User Interface
HoQ	House of Quality
IAEA	International Atomic Energy Agency
IATA	The International Air Transport Association
ICAO	International Civil Aviation Organization
ISO	International Standards Office

LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LORA	Level of Repair Analysis
LRU	Line-Replaceable Unit
MAV	Multi-Attribute value
MoT	Ministry of Transportation and Infrastructure of Canada
MRO	Maintenance, Repair and Operations
MSG	Maintenance Steering Groups
OEM	Original Equipment Manufacurer
PAMELA	Process for Advanced Management of End of-Life-Aircraft
QFD	Quality function deployment
R&D	Research & Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical Substances
RoHS	Restriction of Hazardous Substances
SAE	Society of Aerospace Engineers
SCI	Social Index
SLCA	Social Life Cycle Assessment
SOM	Self-Organizing Map
SRU	Shop Replaceable Unit
SUI	Sustainability Index
TCO	Total Cost of Ownership
UN	United Nations
VFV	Véhicule en Fin Vie

Dedication

I dedicate my dissertation work to my lovely parents, Sadegh and Zahra

Acknowledgements

I would like to express my heartfelt appreciation to my advisor Professor Daoud Ait Kadi for the continuous support of my Ph.D. journey and research, for his motivation, enthusiasm, and immense knowledge. His endless guidance helped me in all the time of research and writing of this thesis. I would like to express my sincere gratitude to my co-advisors, Professor Christian Mascle, his encouragement, kindness and support. His insight, knowledge and valuable comments guided me continuously through my Ph.D. study.

I would like to acknowledge funding from Bombardier, BHTC, CRIAQ, Aluminerie, Alouette, Sotrem-Maltech, BFI, NanoQuebec, MITACS and NSERC.

For someone passionate about experience in industry, joining the Bombardier and design for environment team was a privilege. During the internship, I had this opportunity to work closely with this team and thanks for the conversations and exchanges of ideas during this period. I really appreciate the teams support and the friendly atmosphere of working.

I really appreciate Professor Artiba Abdelhakim, Professor Angel Ruiz, and Professor Diane Riopel for serving on my thesis committee and president of the committee Professor Claire Deschênes.

My deepest appreciation is extended to Université Laval, the Faculty of Science and Engineering and the department of mechanical engineering, beyond them, all the wonderful people that work hard to make our doctoral experience memorable. I would like to thank all of the support and administrative staff of FORAC and CIRRELT.

Furthermore, I appreciate all friends and colleagues in Professor Ait Kadi's research team and graduate students in FORAC Lab for sharing interests, exchanging ideas and developing important friendships. I also want to express my sincere gratitude to all of my friends, who have become my extended family. Last but not the least; I would like to acknowledge my family for their encouragement kindness and supports.

Foreword

This thesis has been realized under the co-direction of Daoud Ait-Kadi Professor at the Mechanical Engineering Department Laval University, Québec, Canada and Christian Mascle Professor at the Mechanical Engineering Department of École Polytechnique Montreal, Canada. It has been prepared as an article insertion thesis.
The thesis includes 11 articles, co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle. In all of the presented articles, I have acted as the principal researcher. As the first author, I have also performed the mathematical models development, coding the algorithms, analysis and validation of the results, as well as writing of the first drafts of the articles. Professors Daoud Ait-Kadi and Christian Mascle have revised the articles to obtain the final version.

The First article entitled "Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects A Research Agenda in Transdisciplinary Context." co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the *Journal of Management and Sustainability*, 3(3), p76, 2013.

The Second article entitled "Toward a Projection model for estimation of End of Life Aircrafts "co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the proceedings of *Fifth international conference of industrial engineering and operation management* (IEOM 2015) Dubai.

The third article entitled "Modeling Robustness of Business Ecosystem of End of Life Vehicles Players" co-authored " by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the *Journal of Sustainable Development Studies*, 4(1).1-35, 2013.

The fourth article entitled "Economic Sustainability of End-of- Life vehicle recycling infrastructure under uncertainty (A fuzzy logic approach)" co-authored by Pr. Daoud Ait-

Kadi and Pr. Christian Mascle has been published in *Industrial Engineering and Systems Management (IESM), Proceedings of 2013* International Conference on (pp. 1-6) IEEE.

The fifth article entitled "End of life Aircrafts Recovery and Green Supply Chain (Opportunities and Challenges)" co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the proceedings of *International conference of Green supply chain* , Arras France , 2014.

The sixth article entitled "Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network" co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in *SAE International Journal of Materials & Manufacturing* 7.1 (2014): 73-83.

The seventh article entitled "Auto manufacturers and applying green practices (The case of End of life Vehicles) "co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the proceedings of the *International Conference on Industrial Engineering and Operations Management* Bali, Indonesia, 2014.

The eighth article entitled "Sustainable Approach to Aircraft Maintenance at Design Stage" co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published in the proceedings of RAMS 2014: *The annual reliability and maintainability symposium* ,Colorado.

The ninth article entitled " A Conceptual Framework for Value Chain Analysis of Aircraft Recycling in the Context of Sustainable Development" , co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle has been published as *SAE Technical Paper* (No. 2014-01-2232).

The Tenth and eleventh (A pair of articles (Part A & B) entitled "Developing an optimization model for End-of-Life Aircraft treatment in the context of Sustainable Development, Lean Management and Global Business" (Part A: Integrated framework for strategic optimization), (Part B: Optimization model, solution approach and application perspective) co-authored by Pr. Daoud Ait-Kadi and Pr. Christian Mascle have been submitted to *the Journal of industrial ecology.*

1. Chapter One

General Introduction

1.1. Background and Problem context

This sub-section gives an overview of the motivation for research and the essential of the problem. The current concerns related to the environmental changes are described and the reflections of industries and business sections, research communities and public will be explained to provide a clear picture of sustainable environment. The waste problem as the result of economic growth is described and necessity for considering life cycle approach and the management of the products at the end of life are described. Finally, the problem of the Aircraft at the end of life which is the main motivation for this dissertation is clarified.

1.1.1. The motivation for sustainable environment

The ecological impacts of human activities and the growth in natural resources consumptions are transferred to a crucial global concern particularly for future generations. According to UN report (UN Report, 2010) the human activity is presently unsustainable and without preventive actions or long term solutions, it could require two planets by 2040. According to this reference, three major elements in economic growth are related to increasing the size of middle class of population, urbanization and the development in global trade or globalization phenomenon. Transportation plays an important role in economic development but at the other side with increasing the demand in international transportation; we face a considerable ecological footprint (Figure 1) which pushes the countries, researchers, industries and communities to establish a systematic approach in order to reduce resource consumptions. Figure 2 illustrates the efforts of four important players to form a sustainable environment. The first group is research community. The increasing of studies, research projects and academic activities in recent years reveals the importance of this subject. Linnenluecke and Griffiths, (2013) provided a systematic review in corporate sustainability field and considered the studies have been done in the period of (1953-2011). Five categories of the research in this context based on this study and the number of papers are shown in Figure 2. Business and industries efforts are included publishing relevant manuals, environmental reports, and eco design activates. The government and authorities also involved in this journey by establishing rules and regulations, green tax and etc. The environmental concerns also absorbed the attention of public communities. The shift in consumer's behavior (buying Eco-friendly products), Media, NGOs or other group's efforts also show the impact of ecological footprint on public.

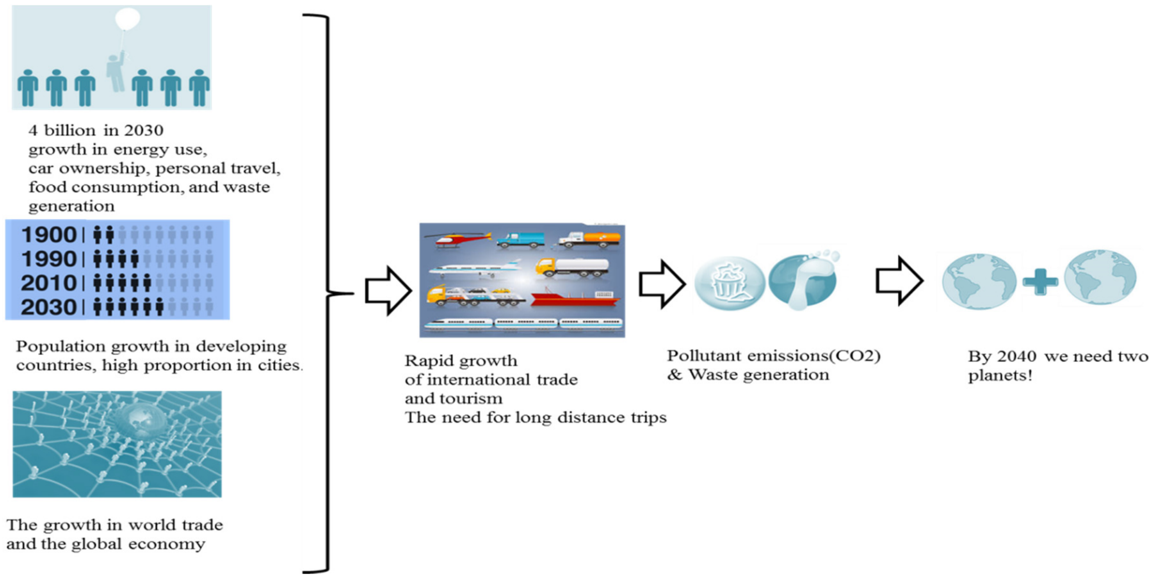


Figure 1 : The ecological challenge

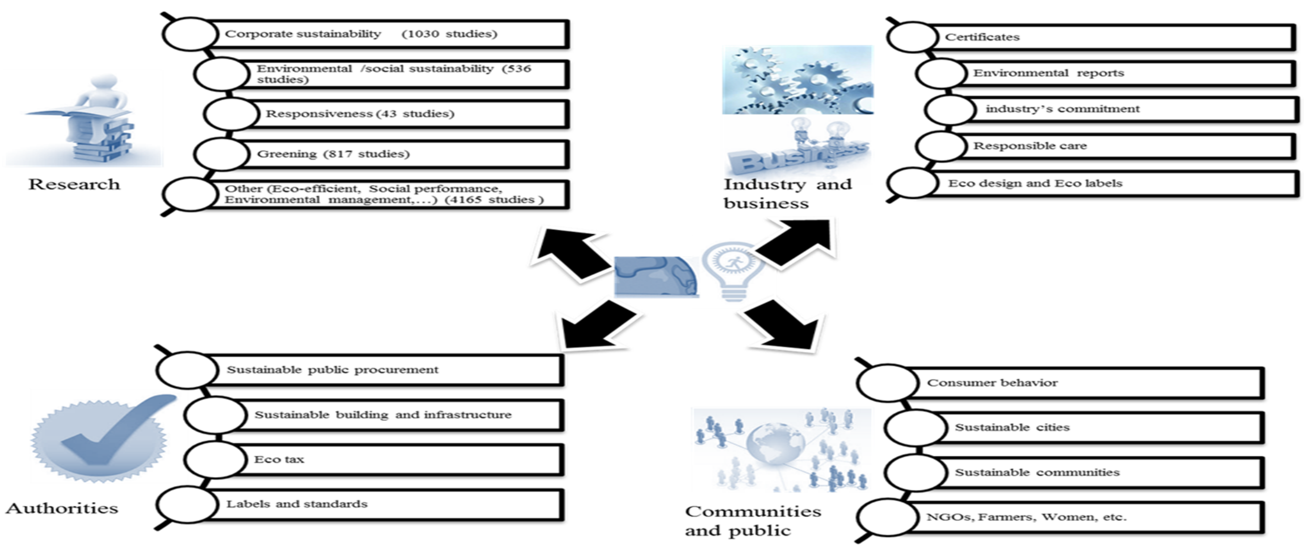


Figure 2 : the efforts of four important players to form a sustainable environment

1.1.2. Life cycle approach and Products at the End of Life (EOL)

Integrating environmental concerns to different parts of product value chain and motivation for life cycle assessment come from different sources and pressures. The customer pressure, competitive forces and legislation are important reasons for companies in involvement in environmental efforts especially eco-efficiency design (Rose, 2000). Outsourcing the manufacturing process is the response of increasing competitions and global market pressure in order to reduce the associated costs and relevant risks. Managing the product until the end of life will be crucial and challenging in this context. When the product has longer life and includes the different regulations, the problem will be more complex (Moorthy, 2013). Reducing ecological impacts of products and effective use of natural resources push manufacturers to have a life cycle approach from design to end of life phase. In this approach, each step of manufacturing process and supply chain as well as product at the end of life is a part of manufacture's environmental responsibility. Life cycle analysis of the product is an approach for assessing the ecological footprint of the product during the whole life cycle. According to ISO-14040 definition, LCA is the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (Cited in Heijungs et al., 2010).

Based on EPA definition, LCA is a technique to evaluate the environmental features and potential impacts related to a product, process, or service, by: Compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential environmental impacts associated with identified inputs and releases and interpreting the results to help make a more informed decision.

Waste management approach is an essential part of international sustainable development strategies. In a life-cycle view, minimization of wastes is main concern. The residual solid wastes and hazardous materials need to be handled efficiently with proper reusing, recycling or recovery solutions. The 3R concept (Reduce, Reuse, and Recycle) summarizes this life-cycle approach to waste (UN report, 2010).

Reducing land-filled material, maximizing recycling, and controlling hazardous materials are important challenges in end of life treatment. Products with different characteristics experience distinct end-of-life strategies. Now, end-of-life treatment systems are developed by industry voluntarily or as a reaction to legislation. However, solutions to this complex subject must integrate both technical and business aspects (Rose, 2000).

Many industries are involved and have already moved in this direction, including automotive and consumer electronics. The End of Life phase of some products is a relatively complex phase in their life cycles. Aircrafts are in this category and the management of its EOL treatments needs a systematic approach. In the next sub-section before explanation of EOL aircraft problem, an overview of sustainability in aviation industry is provided.

1.1.3. The sustainability paradigm in Aviation industry

Aviation provides social and economic benefits for society and global economy (ATAG, 2010). These benefits are not only providing transportation services for passengers around the world but also supporting over 56.6 million jobs across the globe and the role in global economy (Airbus Environment Report, 2013). Hence, the first concentration of aviation is meeting the society needs for transportation and sustaining the relationship with stakeholders. Minimization of greenhouse gas emission and prevention of dangerous interference with climate system is another objective of the sustainable aviation. However, in 2011, aviation contributed around 2% of global CO2 emission (ICAO Environmental Report 2010)but the aircraft manufactures are working on reducing the emission and also improving the quality of air through innovative technologies (Airbus Environment Report, 2013). Another environmental impact of aviation industry is noise. Noise has become a main constriction to air traffic, 60% of all airports considering it as a major problem and the nation's fifty largest airports inspecting it as their principal issue (Antoine & Kroo, 2010). Therefore, limiting and reducing the impacts of aircraft noise is a concern for commercial aviation. Considering the product life cycle and integrating environmental concerns to different phases of the product life cycle is another effort in sustainable aviation context (Figure 3).

The study (Romaniw & Bras, 2012) reports a survey of common practices in aerospace manufacturing industry regarding sustainability. According to this study, the major practices could be divided into two categories: manufacturing practices and facility practices. Manufacturing practices are included product modification and improvement in addition to process modification and improvement, where modification means changing in current products and processes in order to be more sustainable and improvement means making alteration in products or processes in order to be more efficient and leaner. The author divided the facility practices in two groups: regulatory and general. Regulatory refers to mandatory legal codes as well as non-mandatory standards or certifications for lean, sustainable development and environmentally benevolent and finally general practices includes recycling initiatives , environmental awareness workshops or those public activities aligned with environmental stewardship. This research concludes with potential gaps in these practices and highlights that, target environmental efforts appears to be material working and surface finishing with respect to the high energy consumed and chemical waste. However, the component and assembly, re-using, remanufacturing are those practices which seems lack of attention paid to them. Another gap is related to the lack of standards or universal metrics for assessing environmental impacts, so the measurement of value and improvement are not clear and finally, significant lack in regulatory framework, which made the efforts promotional. Synthesis in literature related sustainability of aviation industry shows that there are several challenges with respect to the aircraft recycling which should be addressed in future researches including responsibility of manufacturers, the effective feedbacks for design stage, the different actors in recycling chain, the challenges of re-using and remanufacturing as well as the reverse logistic challenges for aircraft manufacturers.

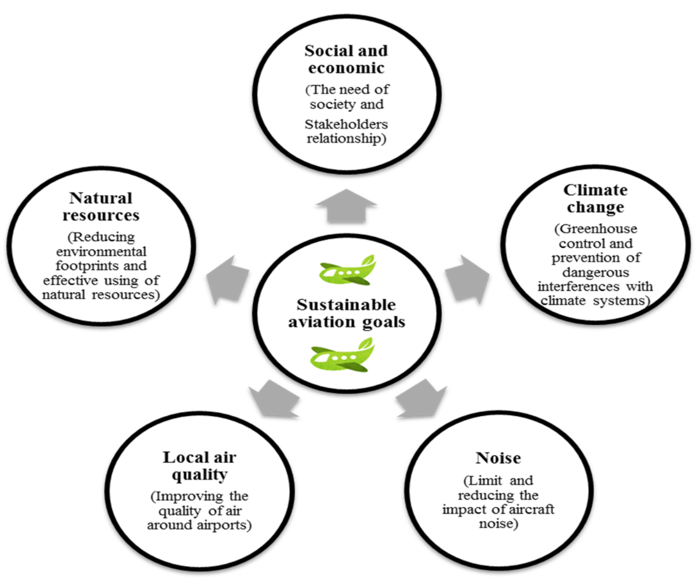


Figure 3 : Sustainable aviation goals

1.1.4. Aircraft at the EOL

Leaving the aircrafts near airports and in desert areas is a common practice in the aviation industry. These abandonments represent a potential significant environmental damage, encourage uncontrolled aircraft dismantling and promote the introduction of parts in aviation through a black market. In the coming years considering the expected increase in retirement of fleet, aviation industry faces a new problem. The rising cost of fuel must also be taken into account, since this factor could force the owners to withdraw aircrafts from services because they are unable to financially support the operating of aircraft with intensive fuel consumption. Fortunately, aircraft owners (rental companies, airlines, banks, part brokers, individuals, etc. . .) are increasingly environmentally conscious. The green image associated with treatment of aircrafts at the end of life based on environmental concerns moved gradually as a criterion of competitiveness on the global market (Siles, 2011). According to (Sainte-Beuve, 2012) at this time, an aircraft is withdrawn from service before the end of its operational life in order to reduce operating costs and the replacing it with a more efficient aircraft. Aircraft recycling at end of life can be considered as a significant financial windfall. Indeed, it is possible to generate near million U.S. dollars, considering only the recycling of materials, regardless of the resale of the reusable parts from aircraft. In addition, green considerations are becoming more important at all levels of the life cycle of products. In this context, the reduction of the environmental impact of the retired fleet through recycling process has an important role for all actors in operation processes of recycling the EOL aircrafts. Moreover, such approach can ensure a long term social benefits. Indeed, the development of this sector and having an infrastructure for recycling can lead many lasting jobs opportunities, which are a factor of social and local development. However, there are some major differences in treatment of the case of EOL aircraft. The volume of EOL aircrafts is very small compared to the volumes of electronics or EOL vehicles. In addition, the residual value of components and materials in aircraft can be very high, depending on the technology of dismantling and disassembly used; aircraft consisting of high quality alloys and spare substantial market value, as engines and landing gear. Moreover, according to estimations from Airbus and Boeing between 6000 and 8000 commercial aircraft will be retired in the next 20 years. The treatment of these aircraft must be economically attractive to produce the value for all actors and thus needs advanced methods and processes.

1.1.5. Motivation for this dissertation

CRIAQ ENV-412 is the name of project which has been initiated with collaboration of industrial partners such as Bombardier, Bell Helicopter, BFI, Aluminerie Alouette and Sotrem-Maltech and universities such as École polytechnique Montreal, McGill and Laval in order to develop general methods and test them to implement profitable recycling processes for end-of-life aircraft and helicopters operated in Canada and in the rest of the world for aircraft and helicopters manufactured in Canada. The objective of Task 2 of this project is update of the models, methods and tools for efficient advanced management and technologies of Aircraft End of life. This aim can be achieved by minimizing the environmental impacts of players involved in Aircraft End of life problem and maximizing economics and social values perceived by them.

This thesis project is defined based on one of sub-projects of Task 2, L1. In page (40/30) of CRIAQ ENV- 412 proposal, the scope of this project has been defined along these lines:

This 3 years project aims at identifying and characterizing value perceived by different shareholders and stakeholders of a value loop (business units, consumers, society). A deterministic design model will reflect how such value can affect design decisions. The objective function of the model will take into account importance accorded to interests of each shareholders and stakeholders.

1.2. The purposes of Thesis & methodology

There are some approaches for treatment of EOL aircrafts which have been practiced by different initiatives but a holistic and systematic approach for management of whole process considering the stakeholders and sustainable development context is lacking or could be improved. EOL aircraft recycling management covers not only technical specifics, but it also requires an integrated strategic approach. Developing a strategy for EOL aircraft treatment in the context of sustainable development is essential in order to sustain stakeholder's value, consider legislation and policy and preserve efficiency and effectiveness of the whole process. In this sub-section, we review the issues and challenges and introduce the research questions and the methodology for tackling these questions and finally the contributions of this research thesis.

1.2.1. The challenges and gaps

End of life recovery of the products such as vehicles or electronic devices are well-developed research filed thus there are several studies which cover the different aspects of this field. But the EOL aircraft recycling is completely a novel topic and there are only few works which address some aspects of this problem. The absence of relevant directives in aviation industry, size of treated materials from End-of-Life aircrafts, the complexity and challenges in fleet recycling process, the multilayered relationship among players are only some aspects that differentiate EOL aircraft problem from the rest of EOL recovery literature.

Heerden & Curran, (2011) addressed the topic of value extraction from EOL aircrafts. The authors tried to answer five important questions about the recycling of the aircrafts: why, when, what, who and where. They focused on the process of EOL aircraft recycling, the components as well as its economics. Franz et al., (2012) provided an assessment of life cycle engineering in preliminary aircraft design. They proposed an interdisciplinary approach in order to integrate the sustainability issues in aircraft design stage. With respect to the recycling and disposal phase, they considered the "Ladder of Lansink" approach to the aircraft dismantling which already proposed by (Heerden & Curran, 2011). In this approach, the first choice from environmental point of view is using the aircraft parts in other aircraft which still being operated. If reusing cannot be applied, the recycling or down-cycling (which refers to chemically combined or physically joined parts) is the choice. If these options cannot be done due to technological restriction then energy recovery by burning can be the solution. And finally, in the event that none of these options are available, landfilling is the last option. Sainte-Beuve, (2012) studies different strategies for dismantling of skeleton of the aircraft. This work examined the difficulty of recycling of the skeleton due to use of mix materials. The author believes that recycling the skeleton is not a process with very high added value, such as parts reselling, though smart sorting can increase the extracted value from this operation. Latremouille-Viauet al., (2010) proposed a mathematical model in order to optimize the effectiveness of the aircraft dismantling process. This research studied which parts must be sorted before shredding and which unites need to be shredded directly. Siles, (2011) developed a decision tool in order to maximize the profit of dismantling process with respect to the sorting stages. This work considered different scenarios for dismantling and introduced a mathematical model in order to show that which scenario can be chosen depending on available time, costs and revenues related to the scenarios. The synthesis in this literature reveals that there is not an integrated approach to EOL aircraft recycling which cover sustainability, global business and value creation concepts at the same time. Moreover, the logistics network management considering economic, environmental and social parameters and optimization of whole recovery process has not been addressed systematically. Hence, to date, there is not a study that looked at the EOL aircraft picture from a holistic perspective. The details about the issues and challenges in the problem are classified in two areas.

1. Complexity Aspect

Choi & Krause, (2005) introduced ‘‘complexity’’ as a key area of managerial consideration in supply chain analysis. Based on the concept of complexity used by Kauffman (1993), Waldrop (1992), and Dooley (2001), they defined the complexity in supply chain analysis as a factor of the number of suppliers in supply base (N), the level of interaction among them (I) and the degree of variation between these suppliers in terms of technology, size or organizational culture (D). Hence, the number of suppliers, their variations and the level of interaction make the operational load for focal company in supply chain management. They analyzed this complexity by defining a supply base which includes the different suppliers and their interactions. In the analysis of EOL aircraft treatment value chain, we face with three bases: process base, performance base and stakeholder's base (Figure 4). If we define the complexity in each base (level) as a factor of number of elements, their interaction and the diversity among them, then the total complexity will be the function of these three levels of complexity. There are different sub-processes in the treatment of EOL aircraft. The relations among these processes and the diversity of these sub-processes in terms of the technology, required human resources, the challenges of implementations, and the geographical location and so on make the first level complexity (Eq.1.1) The second level of complexity encompasses the sustainability, efficiency and effectiveness of this process. The number of aspects in this level (economic, social and environmental level), the trade-off among these different aspects and the diversity of these criteria make the second level complexity (Eq.1.2). The third level includes the different players involved in this problem. The number of players, the interaction among them and their diversity in terms of size, the influence, type of organization and so on form third level complexity(Eq.1.3). Therefore, the total complexity in this problem can be shown as a factor of three levels complexity (Eq.1.4).

$$Com_{level\,1} = f(N_{process}, I_{process}, D_{process}) \quad (1.1)$$

$$Com_{level\,2} = f(N_{performance}, I_{performance}, D_{performance}) \quad (1.2)$$

$$Com_{level\,3} = f(N_{stakeholder}, I_{sstakeholder}, D_{stakeholder}) \quad (1.3)$$

$$Com_{Total} = f(Com_{level\,1}, Com_{level\,2}, Com_{level\,3}) \quad (1.4)$$

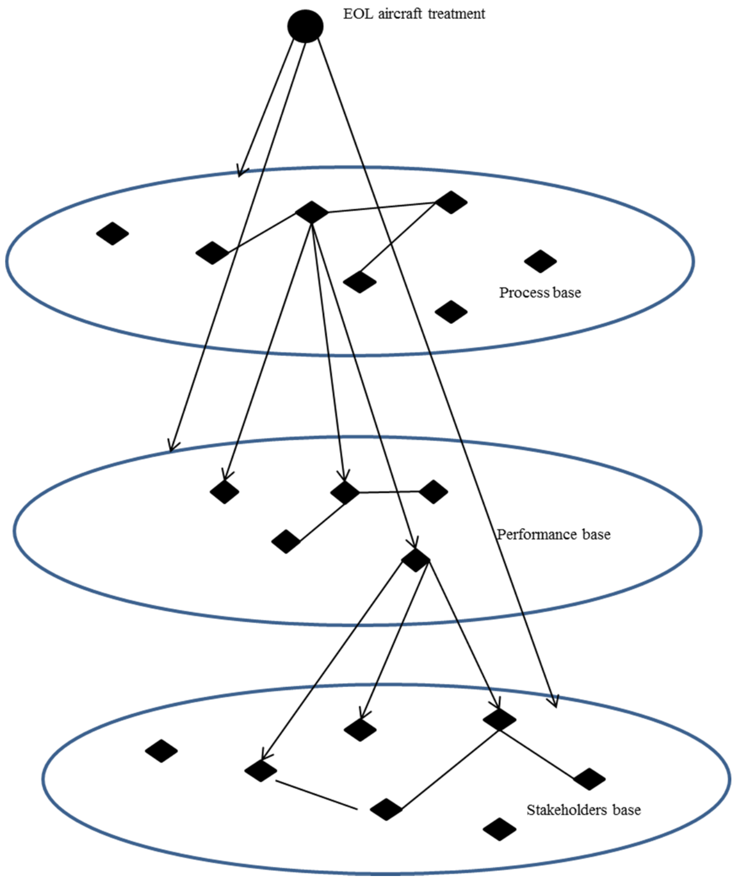


Figure 4 : The complexity in EOL Aircraft treatment

2. Value creation & life cycle Aspect

Except legal necessities REACH (Registration, Evaluation, Authorisation and Restriction of Chemical Substances (EU)) and RoHS (Restriction of Hazardous Substances (UK Directive)), there are no further regulations and directives which force aviation industry to become more environmental friendly. Hence the key driver of producer behavior is generated by the market itself. The new and greener design is important to protect the environment for aircraft operations. Considering long service life, new aviation design takes more than a decade to develop. This indicates the requirements for eco-design practices including green design and production, withdrawal, and recycling of aircrafts and their components originating from repair actions. With these practices, aircraft manufactures be able to minimize the use of raw materials and energies as a result improving the environmental and the social impact of the whole products life cycle. But, the field of eco-design for aircraft and its effects for the whole lifecycle as well for society have not been studied systematically (Morimoto and Agouridas, 2009). The EOL phase of aircraft needs to be considered in whole life cycle of the aircraft (Figure 5). Developing technology for recycling and design for recycling are long term strategies to dealing with the EOL aircraft problem with the key role of manufacturer. The drivers in this context are life cycle approach, clean aviation goals and footprint. Ladder of Lansink emphasizes on prevention before reusing, recycling, energy recovery and landfill options. Therefore, considering eco design strategy for prevention is essential for manufacturers in the context of sustainable development. However, the trade-off among the economic, environmental and social impacts of each step should be considered (Figure 6).

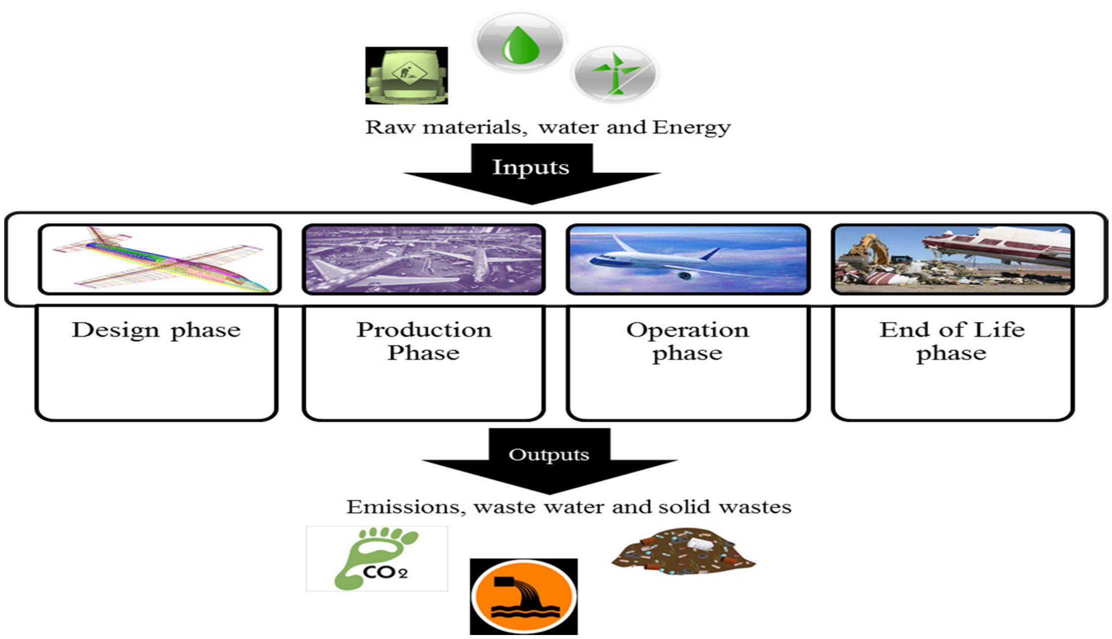


Figure 5 : Life cycle of Aircraft

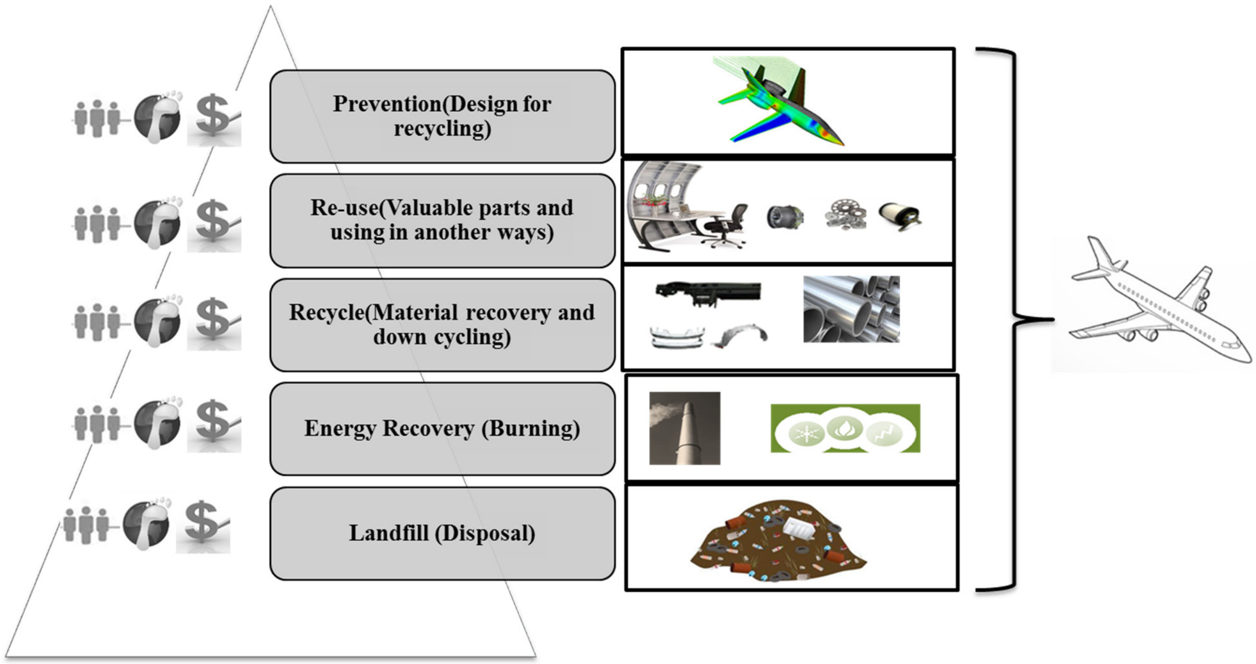


Figure 6 : Ladder of Lansink approach to EOL Aircraft problem

Porter introduced the idea of the value chain in the context of competitive advantage (Porter, 1985). He developed this concept in order to analyze which particular activities may create value for companies. But, Porter's value chain approach is limited to the firm level and ignoring the analysis of the activities outside the company. Gereffi, (1994) developed the global commodity chain concept. This framework has four main elements: input-output structure, regional/international structure, institutional and governance framework. The Gereffi's framework also covers institutional mechanisms and inter-firm relationships. There is not an independent ecological concept for value chains until now (Faße et al., 2009). However, the integration of the environmental thinking into value chain has led to developing some new concepts like green value chain or eco-friendly value chain. But, there is a need to develop a holistic approach to value chain analysis which covers value added activities, governance and inter-firm relationship, regional or international dimension as well as sustainability objectives. To the best of our knowledge, recovery of EOL aircraft is not considered as a value chain and in the context of sustainable development. A holistic perspective to model strategic and managerial decisions considering global logistics, network structure, dismantling strategies, performance management and management of value chain is required. (Figure 7)

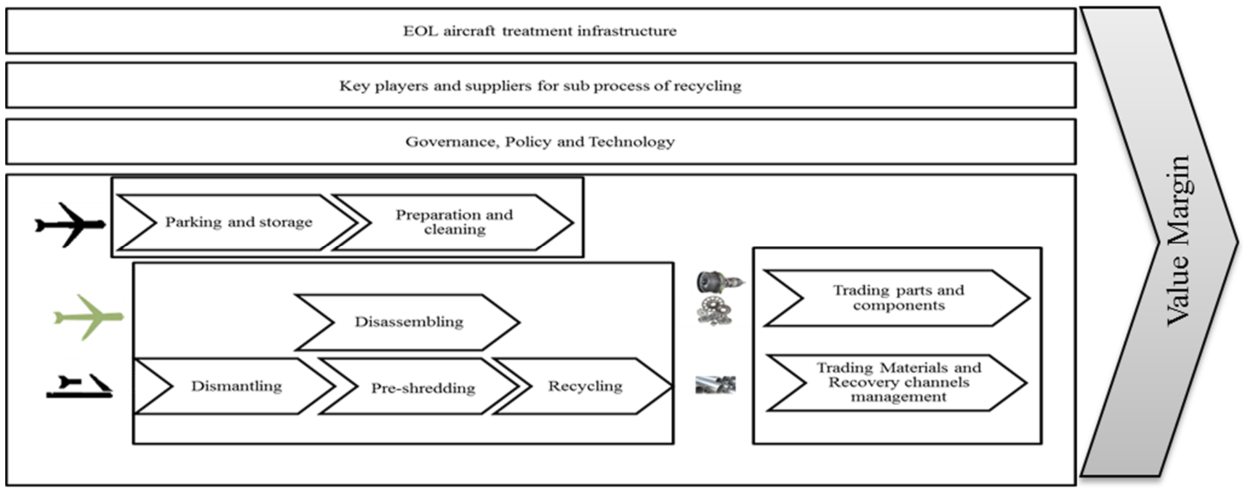


Figure 7 : Value chain of EOL aircraft treatment

1.2.2. Key research Questions

This research seeks to develop certain methodological framework for value chain analysis in the context of sustainable development. We achieved this goal via examining the value through the EOL aircraft recycling process considering all involved stakeholders and requirements of sustainable development. Therefore, the following aspects are addressed:

1. Identifying the context of EOL aircraft recycling and the key players in the problem
2. Identifying the strategic decisions and dynamics of EOL aircraft treatment
3. The role of manufacturers and value creation by integrating EOL problem in design stage
4. Developing an integrated approach for value chain analysis of EOL aircraft
5. Developing a holistic approach to value chain analysis in the context of sustainable development

1.2.3. Research Approach

This section will define the research methods that were used. The research methods utilized in this research include literature review and interview with experts. The literature review is a research methodology that includes examining through books, journals, conference proceedings, dissertations for available information on the area of research. The research area regarding EOL aircraft is completely new. A substantial amount of literature exists in the field of ELV but the main content of literature about the aircraft recycling can be obtained via newspapers and industrial expert's opinions.

The literature is complete in some respects while inadequate in others. A considerable amount of information has been gathered through graduate student projects. The other information has been collected via contacts with professionals during my three months internship in Bombardier Aerospace. The literature has been reinforced with discussions with people involved in industry and CRIAQ project.

1.2.4. Contributions of this Work

The contributions of this thesis can be addressed in four axes which led to the papers published/submitted in scientific Journals or Conference proceedings. Figure 8 represents a summary of these contributions and a brief description of each axis will be described in this sub-section.

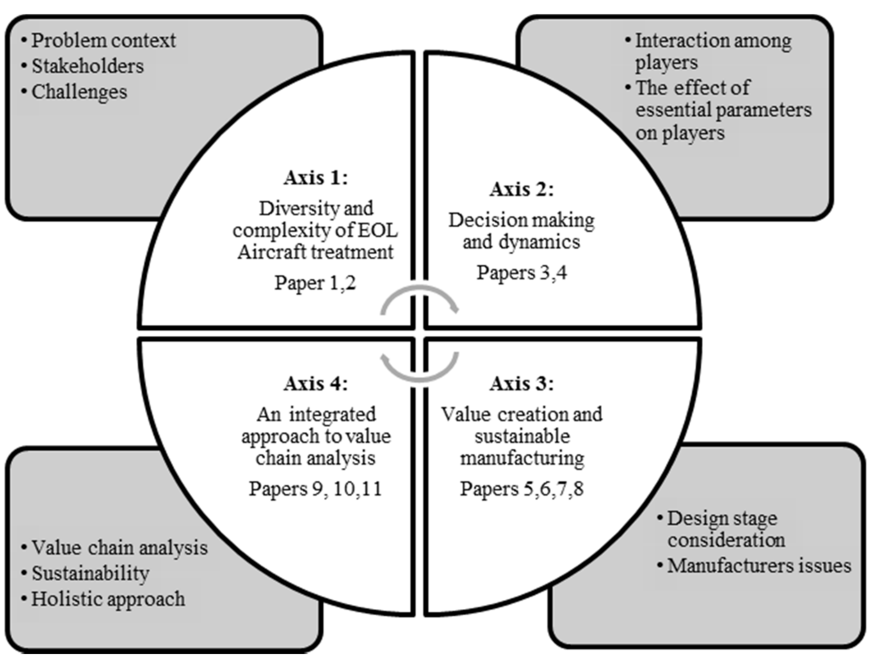


Figure 8 : The contribution of thesis

1.2.4.1. Axis 1

The complexity and diversity of the EOL aircraft recycling including the challenges and problem context are discussed in Paper 1. During the recent decade, considering the directives and regulation in automotive industry, several models and solutions are developed for car recycling. Many studies address the management practices, ongoing innovation or limitation of end of life vehicles treatments in different countries and regions. Several works address reverse logistics with different approaches such as network design and system dynamics. The other studies cover Economic and infrastructure, Shredder Management, Disassembly, Reuse, Recycling, Law and directives and waste management. In addition, different modeling tools and optimization approaches are applied to end of life operational process. In contrast, we face a different, intricate and dynamic context in tackling to the EOL aircraft problem. The reasons are including the absence of relevant directives in aerospace industry, size of treated materials from End-of-Life products, the complexity and challenges in fleet recycling process and potential consequences, the multilayered relationship among partners and players, definition appropriate business model and considering social and environmental aspects. In this work we studied the transdisciplinary concept in EOL aircraft recycling projects and with applying this concept and strategic approach we presented a research agenda for further studies in this field of study. Estimation of the volume of end-of-life aircrafts has a great impact on the implementing of the sustainable policies and passing new regulations. There is few research carried out about the prediction of the number of End of life vehicles. The second paper, with reviewing the existing models, addresses the challenges for estimation of retired aircrafts and proposes an integrated approach for prediction of end-of-life aircrafts.

1.2.4.2. Axis 2

As EOL vehicles problem is a well-developed research filed thus studying the different aspects of this field of study is valuable for developing a framework for our problem. Learning from this area can help us to identify the context of design for recycling and decision challenges of auto manufactures in applying the eco practices for EOL vehicles in a competitive market and considering technology, EOL regulations and the impact on stakeholders. In this axis, the interaction among players, identifying the essential parameters on players and the sustainability of the recovery framework are discussed which led to two papers.

An essential part of modeling and analysis of ELV recycling infrastructure is to capture the dynamic interactions among entities in this network of players. In paper 4, considering the concept of business ecosystem, we proposed a framework to integrate modeling and analysis of the complex interaction among players in automobile recycling infrastructure. With increasing attention to sustainable development, developing a decision support tool in order to evaluate the effects of different source of uncertainties in ELV recycling infrastructure is essential particularly for main players such as dismantlers, shredders, and non-ferrous processors. Paper 4 provides an application of fuzzy rule based model to evaluate the economic sustainability of dismantlers in different scenarios as the result of combination of change in market variables, regulation or technology. The introduced approach in this paper can be applied for shredders and nonferrous processors.

1.2.4.3. Axis 3

The value creation and sustainable manufacturing are considered in this Axis. Design stage consideration and manufactures issue are discussed and led to four papers.

Paper 5 addresses the opportunities and challenges of applying green supply chain for aircraft manufacturers and analyses the different aspects of aircraft at the EOL in the context of green supply chain. The relationship between different operations of aircraft EOL problem and green supply chain elements is shown. This study provides an introduction to a gap of studies related to the green supply chain in aerospace industry based on organizational theory.

Todays with inclusive attention to corporate social responsibility, manufacturers require aligning their green strategies with stakeholder's needs and expectations. In Paper 6, we developed a decision tool to aid manufactures in early stage of design for their green strategy choices. This model provides manufacturers by an evaluation tool to select a portfolio of eco design practices to maximize the value perceived by all stakeholders in a dual life cycle approach including the business product life cycle as well as physical life cycle. A portfolio selection approach has been used to maximize the network value of stakeholders considering the life cycle cost and risk of techniques while satisfying the diversity of allocation resources on eco design practices based on strategic objectives of manufacturers. We also introduced a step by step guideline in order to utilize the introduced methodology for selecting a portfolio of design for EOL practices for aircraft manufacturers.

Fulfilling the legislation pertinent to end-of-life (EOL) products, in addition to sustainability of manufacturers, or license to operation can lead to brands added value and reputation. The competitive advantages of performing the EOL directives need to be assessed in the market framework and the presence of interaction among players. In Paper 7, we developed a model in order to analyze the strategic choice of auto manufacturers in response to EOL directives as the result of interaction of competitors in the market. We used evolutionary game theory for modeling the game between automakers.

An internship project has been also performed in Bombardier that a brief of the objectives of this project are explained here and also the paper 8 was written based on this experience.

Maintenance is an important part of aircraft LCA. The literature shows that considering this phase in LCA is so challengeable and until now there is not any study to address the whole maintenance operations in LCA. The reason is that the data gathering for this phase is so complex. Therefore, data inventory of this phase in order to insert to LCA of aircraft is valuable. The goal of the project was to collect and prepare the data in order to insert in LCA of one product of the company. The data was prepared and some consideration for maintenance manual has been also provided. The boundary of system based on ISO 14044 requirements are clearly defined and the excluded and included items have been addressed. The challenges for data preparation and the related recommendation have been addressed. The data for two types of maintenance, scheduled maintenance and unscheduled maintenance were analyzed and relevant challenges in each category have been addressed. For maintenance manual consideration, a literature review has been conducted. The existing experiences of manufacturers or other studies aligned used in order to develop a framework for addressing environmental concerns in maintenance manual. A detailed example for Engine has been done and a multi objectives model proposed in order to optimize maintenance operations based on three objectives of reliability, operational costs and environmental performance. The other existing company's manuals have been studied and the gaps in the manual and the way for addressing environmental considerations in these manuals have been suggested. This information can help company to apply the Eco-friendly concepts in their manuals and therefore can improve the sustainability performance of the company.

1.2.4.4. Axis 4

Axis 4 covers integrated approach to value chain analysis of EOL aircraft problem. Papers 9, 10 and 11 are the contributions in this part. Paper 9 introduced a methodology for analyzing the value chain in the context of sustainable development. The value chain of the EOL aircraft recycling was selected to show the application of the proposed approach. This approach has four main steps: identifying the value chain and the problem context, sustainability analysis based on triple bottom line theory, identifying the policy framework and network governance and finally performance measurement in order to provide recommendations regarding effectiveness, efficiency and stability across the value chain. The implications of this study are both theoretically and practically. From theoretical perspective, it proves a starting point to develop an integrated framework for analysis the value chain in the context of sustainable development. From practice view, it makes guideline for analyzing the process of EOL aircraft recycling.

In papers 10,11 (A pair of Papers in two parts A, B), we presented a novel holistic optimization framework and multiobjective mathematical model based on sustainable development, lean management and global business environment for EOL aircraft treatment. This framework provides an integrated approach to model strategic and managerial decisions considering global logistics, network structure, dismantling strategies, performance management and management of value chain. This framework is flexible to incorporate the different stakeholders in decision making process via an interactive procedure. This study provides many possible outlooks in this context to enrich the literature of EOL aircrafts as a new aerospace industry's challenge and opportunities.

Each of the next four chapters will be dedicated to one axis described above. Last chapter, summarizes the main research points of this dissertation. It summarizes the crucial lessons resulting from the research. Furthermore, this chapter introduces prospects for future research.

1.3. Conclusion

In this chapter, the background of the problem and motivations for this thesis was presented. The main issues and challenges regarding EOL aircraft treatment problem were discussed and the contributions of thesis and the outline have been provided.

References

Antoine, N. E., & Kroo, I. M. (2004). Aircraft optimization for minimal environmental impact. *Journal of aircraft*, 41(4), 790-797.

Choi, T. Y., & Krause, D. R. (2006). The supply base and its complexity: implications for transaction costs, risks, responsiveness, and innovation. *Journal of Operations Management*, 24(5), 637-652.

Dooley, K., 2001. Organizational complexity. In: Warner, M. (Ed.), *International Encyclopedia of Business and Management*. Thompson Learning, London

Faße, A., Grote, U., & Winter, E. (2009). Value chain analysis methodologies in the context of environment and trade research (No. 429). *Discussion papers*//School of Economics and Management of the Hanover Leibniz University.

Franz, K., Hörnschemeyer, R., Ewert, A., Fromhold-Eisebith, M., Böckmann, M. G., Schmitt, R., ... & Reichmuth, J. (2012). Life Cycle Engineering in Preliminary Aircraft Design. *In Leveraging Technology for a Sustainable World* (pp. 473-478). Springer Berlin Heidelberg.

Gereffi, G. (1994b): The organization of buyer-driven global commodity chains: how U.S. retailers shape overseas production networks. In G. Gereffi and M. Korzeniewicz (ed.) (1994): *Commodity Chains and Global Capitalism*. Westport: Praeger, pp. 95-122.

Heijungs, R., Huppes, G., & Guinée, J. B. (2010). Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. *Polymer Degradation and Stability*, 95(3), 422-428.

ISO Environmental management – life cycle assessment – principles and framework (ISO 14040) ISO, Geneva (2006)

Kauffman, S., 1993. The Origins of Order: Self-Organization and Selection in Evolution. Oxford University, New York.

Linnenluecke, M. K., & Griffiths, A. (2013). Firms and sustainability: Mapping the intellectual origins and structure of the corporate sustainability field. *Global Environmental Change*, 23(1), 382-391.

Morimoto, R., & Agouridas, V. (2009). Supporting Aircraft Manufacturers to Formulate and Implement Sustainable Development Strategies Systematically. Transportation Research Record: *Journal of the Transportation Research Board*, 2106(1), 12-19.

Porter, M. (1985): Competitive Advantage, London: Macmillan

Romaniw, Y., & Bras, B. (2012). Survey of Common Practices in Sustainable Aerospace Manufacturing for the Purpose of Driving Future Research. *In Leveraging Technology for a Sustainable World* (pp. 485-490). Springer Berlin Heidelberg.

Rose, C. M. (2000). Design For Environment: A Method for Formulating Product End-Of-Life Strategies. Ph.D. Thesis, Stanford University.

Siles, C. (2011). Aide à la décision pour la gestion d'un parc d'avions en fin de vie (Master dissertation, École Polytechnique de Montréal).

UNDESA, 2010, Trends in Sustainable Development - Towards Sustainable Consumption and Production 2010-2011

Van Heerden, D. J., & Curran, R. (2011). Value Extraction from End-of-Life Aircraft. Encyclopedia of Aerospace Engineering. Wiley.

Waldrop, M., 1992. Complexity: The Emerging Science at the Edge of Order and Chaos. Touchstone, New York.

Sainte-Beuve, D. (2012). Évaluation de différentes stratégies de démantèlement de la carcasse d'un avion Master dissertation, École Polytechnique de Montréal).

2. Chapter Two

Diversity and complexity in ELV recycling Value chain

This chapter is dedicated to the following articles:

"Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects a Research Agenda in Transdisciplinary Context "published in Journal of Management and Sustainability, 3(3), p76 , 2013

"Toward a Projection model for estimation of End of Life Aircrafts" has been published in the proceedings of Fifth international conference of industrial engineering and operation management (IEOM 2015) Dubai,

The titles, figures and mathematical formulations have been revised to the keep the consistency through the thesis.

2.1. Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects A Research Agenda in Transdisciplinary Context

2.1.1. Résumé

Le nombre d'avions en fin de vie augmente sans cesse. Les pratiques de la gestion innovante des avions en fin de vie peuvent être considérées dans un contexte transdisciplinaire. Compte-tenu de la dynamique et la multi-dimensionnalité de projets de recyclage d'avions, les systèmes de gestion conventionnelle peuvent ne pas être suffisamment outillés et adaptés. L'objectif principal de cet article est de mettre en place des pratiques qui prennent en charge divers aspects de la dynamique et de la transdisciplinarité des projets de recyclage d'avions en fin de vie (EOLARP) dans un cadre conceptuel stratégique. Pour cela, nous proposons quatre éléments principaux qui définissent notre modèle conceptuel constitué d'un modèle d'affaires, du marché et de l'industrie, la gestion des connaissances et les indicateurs de performance. Ces quatre sections, constituent la plateforme pour aborder les questions essentielles dans l'écosystème d'affaires, qui a besoin d'une approche intégrée de différentes disciplines et acteurs (joueurs). D'autres études et travaux dans chaque domaine sont très utiles pour surmonter les difficultés auxquelles sont confrontés les gestionnaires et les partenaires stratégiques dans EOLARP.

Mots Clés: Avion, Projet de recyclage des produits en fin de vie, approche stratégique, transdisciplinaire

2.1.2. Abstract

The number of planes at the end of life is increasing. Innovative management practice of aircraft at the end of life can be considered as a transdisciplinary context. Moreover, regarding dynamics and multidimensionality of aircraft recycling projects, conventional management systems cannot be sufficient and responsive. The purpose of this paper is to address a research agenda that support various aspects of dynamics and transdisciplinarity of end of life aircraft recycling projects (EOLARP) by a strategic conceptual framework. Four sections of the framework including business model, market and industry, knowledge management and performance measurement make a basis for addressing the essential issues in EOLARP business ecosystem, which needs an incorporated approach of different disciplines and players. Further studies and works on each arena in this framework are valuable in overcoming difficulties facing managers and strategic partners in EOLARP.

Keywords: aircraft, end-of-life recycling project, strategic approach, transdisciplinary

2.1.3. Introduction

In the global market forecast of Airbus for the period 2009–2028, 8453 aircraft are projected to be retired (Heerden& Curran, 2010). Based on Boeing's report, the potential market for aircraft disposal will be nearly 6000 by 2028 (Green sky, aviation and the environment, 2010). A substantial and novel industry problem has occurred as a result of large numbers of useless aircraft and the related environmental issues (Heerden& Curran, 2010). Different research groups, companies, projects, associations or initiatives work on end of life aircraft problem. The solutions to this important topic must integrate the different disciplines, field of studies and expertise. End of life vehicle solutions are well developed during the recent decade. In contrast, a review of the literature reveals that little empirical research has addressed main issues in business ecosystem of aircraft recycling projects. The absence of relevant directives, size of treated materials from End-of-Life products, complexity in fleet recycling process, multilayered relationship among partners and players are only some of challenges facing the aerospace industry in relation to end of life aircraft problem.

Defining appropriate optimization tools, decision models and conceptual frameworks in business ecosystem of aircraft recycling with considering economic, social and environmental aspects is a smart way for dealing with these challenges.The purpose of this paper is to address a research agenda that support various aspects of dynamics and transdisciplinarity of end of life aircraft recycling projects (EOLARP) by a strategic conceptual framework.

The authors of the present paper are involved in one of these projects and the main idea of this study comes from the necessity of integrating approach for dealing with strategic aspects of aircraft recycling problem and the lack of literature in this area.The outline of this paper is as follows: In next part, we present an overview of aircraft end of life problem. Then we explain the transdisciplinary and strategic approach and provide a conceptual framework that addresses these approaches in four sections including business model, market and industry, knowledge management and performance measurement. Finally, we conclude with some comments and topics for further research.

2.1.4. EOLA Problem

Reducing resource consumption to preserving the natural environment for future generations is a goal for companies and countries in the sustainable development context. The motivations for designing align with environment come from different sources and pressures. The customer pressure, competitive forces and legislation are important reasons for companies in involvement in environmental efforts especially Eco efficiency design (Rose, 2000). Waste management is crucial as landfills close and populations grow (Pohlen& Farris, 1992). Therefore, reducing landfilled material, maximizing recycling, and controlling hazardous materials are important challenges in end of life treatment. Products with different characteristics experience distinct end-of-life strategies. Now, end-of-life treatment systems are developed by industry volunteers or as a reaction to legislation. However, solutions to this complex subject must integrate both technical and business aspects (Rose, 2000).

According to Heerden& Curran (2010), over the years the aircraft depreciate in value. The cost of maintenance and repair will be increased. Customer satisfaction and reduced fuel consumption are the other aspects of the decision that aircraft operation is no more acceptable.When the owner comes to this decision it faced by several options. After storage time, if the aircraft is worth more than its parts it can be sold as a flyer. If this option is not valuable the aircraft has to be dismantled, reused or disposed.

The overall process of parting-out an aircraft is shown in Figure 9. Numerous important components can be retained before dismantling, recycling or disposal. Engines, landing gears, avionics, and electronic motors are the most common parts which may be reused. Doors, wings, interiors can be used for training purpose (The Aircraft at End of Life Sector). Recycling the material is the other aspect of end of life solutions. Four major classes of materials ranging from low cost interior materials to high performance alloys and composites used in aircraft construction. For old models, the aluminum is main material with a high achievement in recycling technologies but in new models with using composites, the recycling is challengeable.

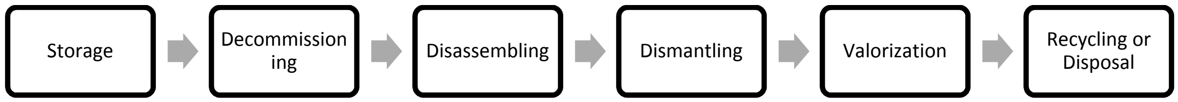


Figure 9 : The process of parting-out an aircraft

Aerospace original manufacturers have a long history of looking for ways to reuse or recycle aircraft and their components. In the past, at least 50 percent of the material used in aircraft construction was reused or recovered (Watson, 2009). Different companies worked on this problem during recent decade. Based on the core business of these companies, they follow different strategies, practices and process for implementing the end of life solutions (Siles, 2011). The two largest airframe manufacturers, Airbus and Boeing, are at the head of research and main projects in this field. Airbus PAMELA project has successfully confirmed that as much as 85 percent of an aircraft by weight can be recovered for recycling (Watson, 2009). Boeing has taken a leadership role in aircraft life cycle and end-of-service recycling strategies for more than 50 years. Aircraft Fleet Recycling Association, AFRA, is a global consortium of more than 40 companies that provides environmentally responsible options for aging aircraft. This includes maintaining and reselling reliable airplanes and returning them to service. Safe parts recovery, scrapping and recycling services are available for airplanes that cannot be returned to service (Boeings environmental report, 2010). In addition to these initiatives, there are some different companies that provide services in this field. Table 1 shows key information regarding these initiatives.

Table 1 : The relevant initiatives in Aircraft end of life solutions

Research Group; Company or Association	Location	Scope of work	Strategies
TARMAC AEROSAVE	France	Decommissioning-dismantling-	Disassembly by TARMAC sell by customer or TARMAC (Siles, 2011)
AFRA	USA	Accreditation Body, Developing Best Practices	In absence of directives, providing a framework and guidelines for end of life business solutions
AELS	Netherlands	Decision Making Solutions	Aircrafts are disassembled but remained the property of the client, it can find the market and sell the parts (Siles, 2011)
ASI	UK	Disposal –Parting Out- Dismantling	Aircrafts are disassembled and delivered to the customer (Siles, 2011)
EVERGREEN TRADE INC	UK	Disposal –Parting Out- Dismantling	Disassembly by EVERGREEN, sell by customer or EVERGREEN (Siles, 2011)
BARTIN AERO RECYCLYING	France	Disposal –Parting Out- Dismantling	Disassembly by another company and recycling by BARTIN (Siles, 2011)
WINGNET	UK	Material Research	Providing a research atmosphere for exchange the research regarding material recycling innovation

Regarding above description, environmental impact concerns, eco efficiency design, technical and business aspects, corporate responsibility and customers trust, legislation and associated authorities boundaries are only few various areas in EOLARP that should be addressed properly to achieve the objectives of these projects. In addition complexity and difficulties are growing more in swiftly changing these areas.

North & Macal (2007) believe that markets, particularly those far from the standard forms analyzed in economic theory (for example, perfect competition, monopoly, and oligopoly) and social systems, especially those within industrial and government organizations, are examples of system, which have been complex. Hence, second hand part market of aircraft components, the role of local or global authorities and the lobbying interface among different stakeholders are the other factors, which intensify the complexity in these projects.The conceptual framework presented in this study provides a starting point for a more structured analysis of thought-provoking issues in EOLARP.

2.1.5. Transdisciplinarity in EOLARP

"Transdisciplinarity is a collective understanding of an issue. It's created by including the personal, the local and the strategic as well as specialized contribution to the knowledge" (Brow et al., 2010, p4). Thompson Klein (2004) states that transdisciplinarity has become a main imperative across all sectors of society and knowledge domains and an important way of thought and action. Figure 10 presents the difference among interdisciplinarity, multidisciplinary, and transdisciplinarity. This illustration of transdisciplinary clears up that in interdisciplinary and multidisciplinary, current field of studies simply mutually impact each other, essentially making intersections in two dimensions. In transdisciplinarity, a new transdisciplinary discipline with its own theoretical structure is created over dynamic cooperation and amalgamation of different disciplines.

Chiesa et al. (2009) remark that transdisciplinarity is a dynamic approach by which different disciplines are linked and arise to a new discipline. Table 2 shows the unique characteristics of transdisciplinary and the related evidence in an EOLA research project.

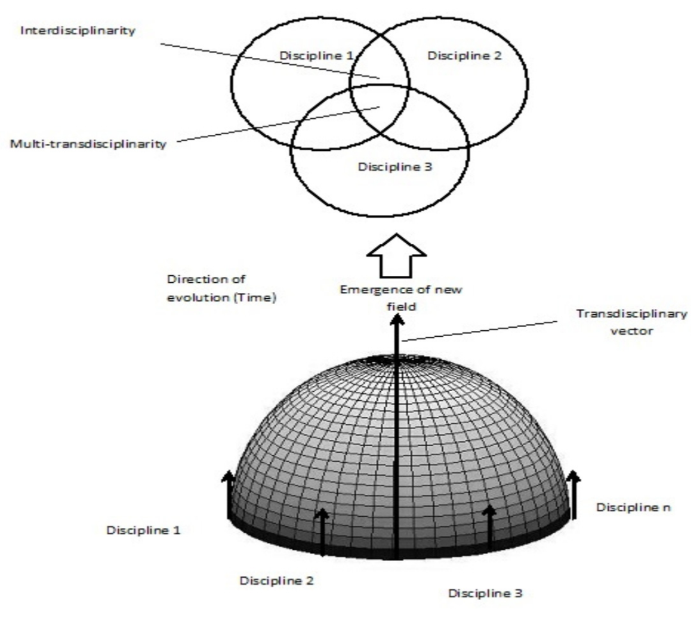


Figure 10 : The difference in the concepts or transdisciplinarity and interdisciplinarity (multidisciplinarity)

Note: (a) Interdisciplinarity (multidisciplinarity). (b) Transdisciplinarity. Based on: Koizumi, 1999 cited inChiesa et al. 2009, p18)

Table 2 : The transdisciplinary features in EOLA research project

	Transdisciplinary aspects	Author(s) (Cited in Brow et al., 2010, pp.18-19)	EOL aircraft research project
1	Complexity in sciences	Somerville & Rapport (2000)	Design for disassembly, material selection, dismantling and recycling technologies, separation techniques, sorting techniques
2	Defined from complex and heterogeneous domain	Lawrence (2004)	Mechanical engineering, aerospace engineering, material science, industrial engineering, business and economy, environmental science
3	Acceptance of uncertainty	Klein (2004)	Bogus part (uncertified parts in second hand markets), global trends, Global fleet growth, passenger traffic growth, aircraft models being offered on the market, investment in maintenance
4	Intercommunicative action	Klein (2004)	Knowledge exchange among industrial partners and research professionals by regular meetings, internships, workshops and so on, using the results of sub-projects in other tasks
5	Result of inter-subjectivity	Desprès et al. (2004), Klein et al. (2001)	
6	Close and continues collaboration during all phases	Desprès et al. (2004)	
7	Action oriented	Desprès et al (2004)	Validation and verification of the developed models and application in industry, building experimental platform for applying the results of research project
8	Linkage between theoretical development and professional practices	Lawrence (2004)	Participating of industrial partners in all phases of project from proposal definition to final pace of the project
9	Addressing real world problems	Pohl, & Hirsch Hadorn (2007)	New industry problem in dealing with large numbers of useless aircraft and related environmental issues

Max-Neef (2005) describes transdisciplinarity via comparison with the other approaches such as multidisciplinarity, pluridisciplinarity and Interdisciplinarity. He highlights that in multidisciplinarity approach the members perform their analysis disjointedly and the result being a set of reports attached together, without integrating synthesis. In pluridisciplinarity cooperation exists among disciplines without coordination. Interdisciplinarity is structured at two hierarchical levels. Therefore, it implies coordination of a lower level from a higher one.

The author introduces a pyramid graph to show the transdisciplinary approach. In this graph from bottom to top, the author illustrates the transdisciplinarity as a result of coordination among all hierarchical levels. He names the lower level, empirical level. This level refers to what exists. The second level is purposive level and refers to what we are capable of doing. The third one is what we want to do and names it, normative level.

Finally, the higher level of pyramid refers to what we must do and the value level. He explains that any compound vertical relations containing all four levels, describes a transdisciplinary action. Based on this conception, we proposed a pyramid graph that demonstrates the transdisciplinary approach in EOLARP (Figure 11).

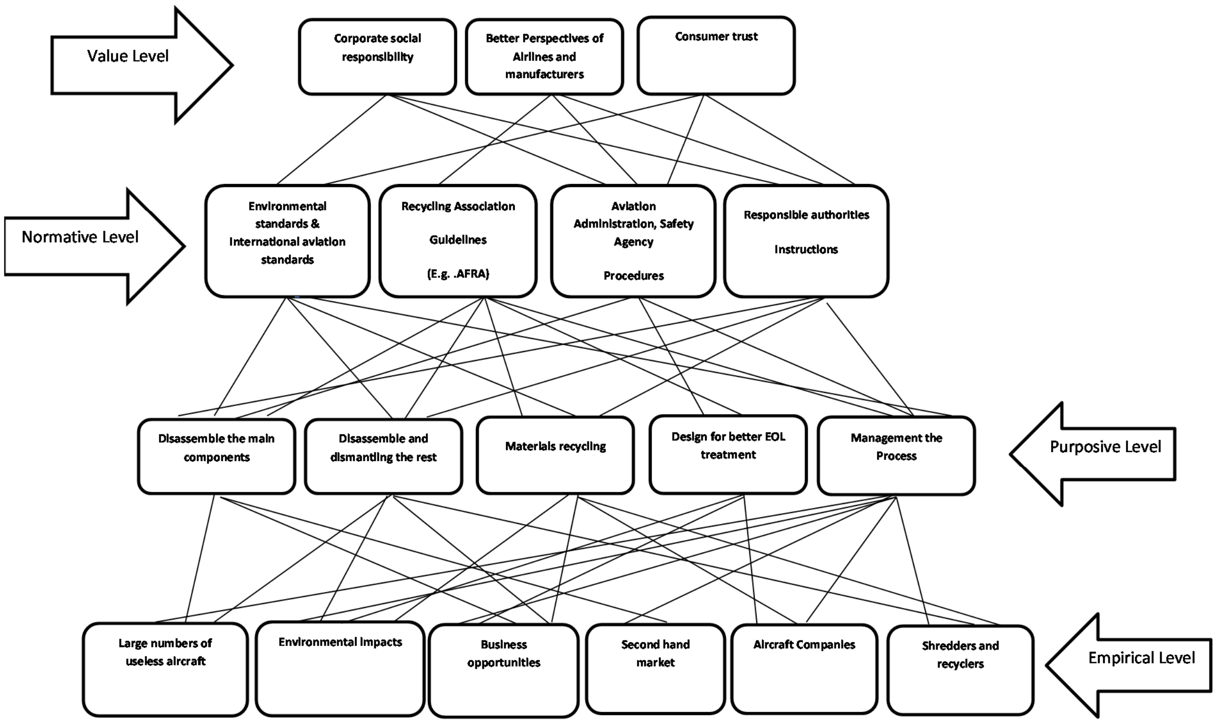


Figure 11 : Transdisciplinary approach in EOLARP

At the lower level, we have the end of life problem and associated issues. Large number of useless aircrafts and connected environmental impacts, the second hand part market and related safety issues in monitoring, tracking and certification. In this level we have also the business opportunities related to end of life aircraft treatment, players in the problem and their opportunities and concerns. For example, for aircraft companies, the reputation or market image in one side and the design in the other side are concerns. The business profits or the technologies boundaries are the other aspects of what exits. The succeeding level is purposive level. In this level we have technological and solution disciplines such as the disassembly of components, the dismantling of the rest parts, recycling materials and management the whole process. The next level is normative level and what we want to do. This level covers all regulations, standards, instructions or guidelines that should be followed to achieve the harmless and even impeccable management process as possible. But it's not enough to meet the expectations of various stakeholders in the project. The higher level of this pyramid or value level involves the final aims of all players containing the social responsibility, better perspective of airlines and manufacturers and finally consumer trust.

2.1.6. Strategic Approach to EOLARP

According to Bower (1970) and Ackoff, (1970) "strategic decisions deal with novel and complex sets of interdependent problems facing the organization" (Shrivastava, 1985, p.98). In addition, we need to have attention in noneconomic factors in decision making. Svendsen & Laberge (2005) explain that new complex reality of the 21st century with increasing sustainability socioeconomic and environmental challenges needs the development of a new way of thinking and engaging with stakeholders. Traditional strategy frameworks were neither helping managers develop new strategic directions nor were helping them understand how to form new opportunities in the core of so much change (Freeman &McVea, 2001, p3).

Freeman &McVea (2001) believe that management should know the needs of stakeholders to set the boundaries of actions. Hence the conventional approach for project management, with focusing on efficiency aspect such as time, budget and quality cannot response the requirement of partners in the project. Project management is a complicated and multidimensional concept. In order to evaluate a project's success, it's needed to understand the different dimensions and address different time frames from very short to very long. Each project has its own specific dimensions, and their relevant importance will vary (Shenhar et al., 2001, p720).

Shenhar et al (2001) suggest that strategically managed projects are focused on attaining business results; however, operationally managed projects are focused on getting the job done. Stefanovic & Shenhar (2007) used a new three-dimensional maturity model, which evaluates projects according to the emphasis on operational excellence, strategic focus, and inspired leadership. They studied how the level of maturity of the project on each dimension related to project success. The authors believe that strategic focus seems to be a key element in achieving customer satisfaction, business success, future prospects, and overall success.

In a study by Shenhar (2004), the relationship between the type of the project and the importance of the strategic focus are explained based on four criteria: the level of novelty, complexity, technology and pace.

Concerning, the uncertainty, complexity and novelty of EOLARP, having a strategic approach can help managers to tackle with the difficulties and challenges in these projects. Figure 12 illustrates this approach. In first layer of this figure we have the key elements of strategic management. These elements based on Johnson & Scholes (1984) are in three interrelated categories including strategic analysis, strategic implementation and strategic choices. The second layer of this figure is the results of strategic focus in project management approach (Stefanovic & Shenhar, 2007).The third layers show four dimensions, which proposed as the elements of strategic approach to EOLARP in this research. In this layer the strategic management elements of each dimension as well as the results are shown. In the other word, the four aspects in third layer are the building blocks of our conceptual framework, which will be explained in more details in next part.

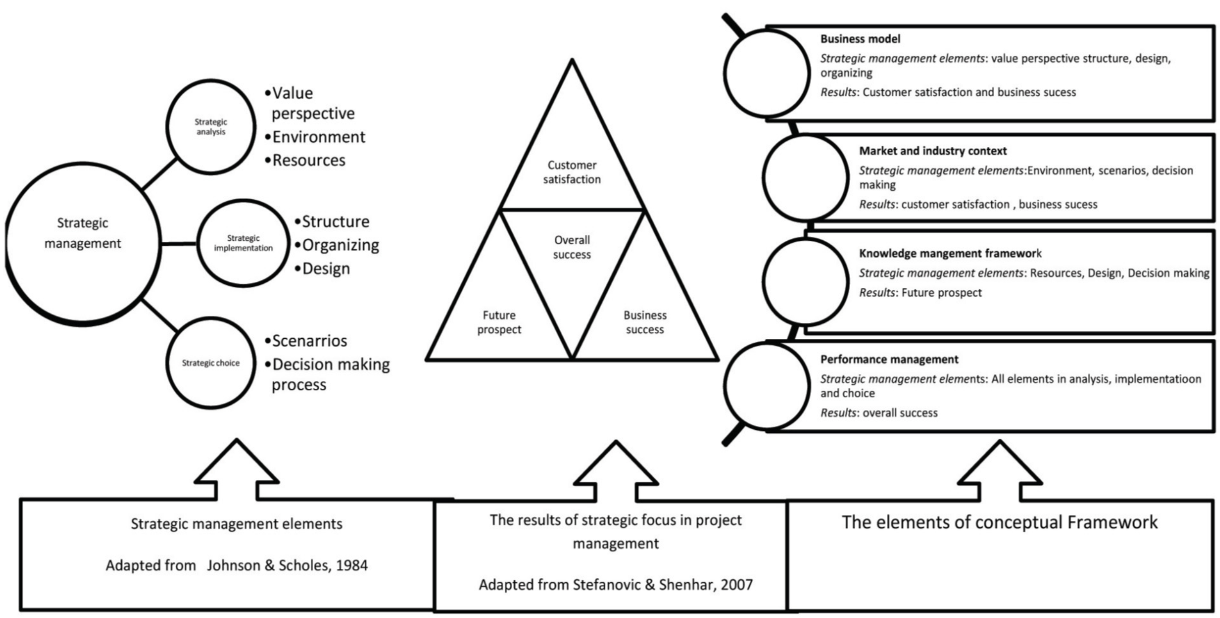


Figure 12 : Strategic approach

2.1.7. The Conceptual Framework

Figure 13 illustrates the conceptual framework, which reflects strategic approach to EOLARP in transdisciplinary context. We focused on four elements in these projects: Business model, knowledge management framework, market and industrial context and performance management. Value proposition and operating model are two important aspects of each business model. Based on challenges in setting targets, the variety of stakeholders, their value perspective and the model for value chain and organization, business model is the first element, which should be considered in this conceptual model.

Addressing business issues in aerospace industry is more complicated and different rather than other industries. Several factors are involved in this complexity including the role and action of government, absence of normal competition to balance the supply and demand, lifecycle of products and important equipment such as engines, aftermarket sales, spare part and maintenance markets, intricate relationship between original manufacturers and upstream value chain partners and the effect of other macroeconomic factors such as oil price volatility, declining traffic and evaporating aircraft finance (Buxton et al., 2006).

As a result, market and industry context is the second portion of our conceptual framework. The knowledge structures, knowledge sharing among multiple players, the different field of sciences, skills and know-how and the barriers and limitation for effective intercommunication in EOLARP are the reasons for selecting knowledge management as a part of our model. Lastly, Performance measurement as an important element of effective planning and control with considering the different perspectives and metrics in a basic model is illustrated.

Hadornet al. (2007) in handbook of transdisciplinary research explained the complexity and diversity of transdisciplinary in the following way:

“Complexity is used for the interrelations among heterogeneous dimensions, or plural values and norms. Diversity: means that empirical dimensions relevant to describing and analysing processes are heterogeneous in the sense that they belong to different disciplines or to the perceptions of different actors and that there are plural values and norms that do not fit together in a systematic way.”

Concerning different stakeholders in EOLARP, compound relationship among these players and policy making with parameters that changed with time, dynamics aspect is another feature for studying each element in our conceptual framework. As a result, in second layer of this framework we have three elements of complexity, diversity and dynamics. In third layer we have three aspects of sustainable development, which play an imperative role in EOLARP.

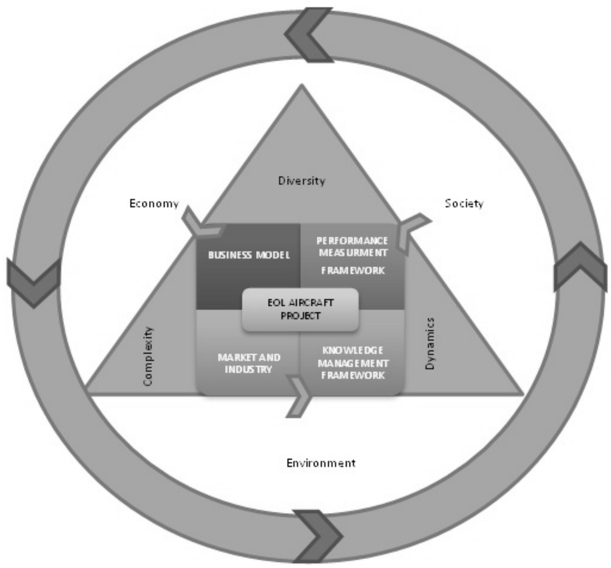


Figure 13 : The conceptual framework

2.1.7.1. Business Model

The business model aids as a building plan that allows designing and realizing the business structure and systems that establish the operational and physical form of an organization (Ostenwalder et al., 2005). Business models aid to capture, visualize, understand, communicate and share the business logic among stakeholders (Ostenwalder et al., 2005). Visual system benefits in handling the complexity (Rode, 2000), the process of modeling social systems and understanding the relationship among its elements (Morecroft 1994; Ushold& King 1995) and helping managers to communicate and sharing their understanding of a business among other stakeholders (Fensel, 2001) are the advantages of business model (Cited in Ostenwalder et al., 2005).

In order to better understanding of the business perspective of EOLARP, we explain the stakeholders involved in this environment. Figure 14 shows the different players in a typical EOLARP. As shown in this figure, EOL enterprise is a main actor in this ecosystem. This body is responsible for designing, performing and managing the whole process of EOL aircraft treatment.

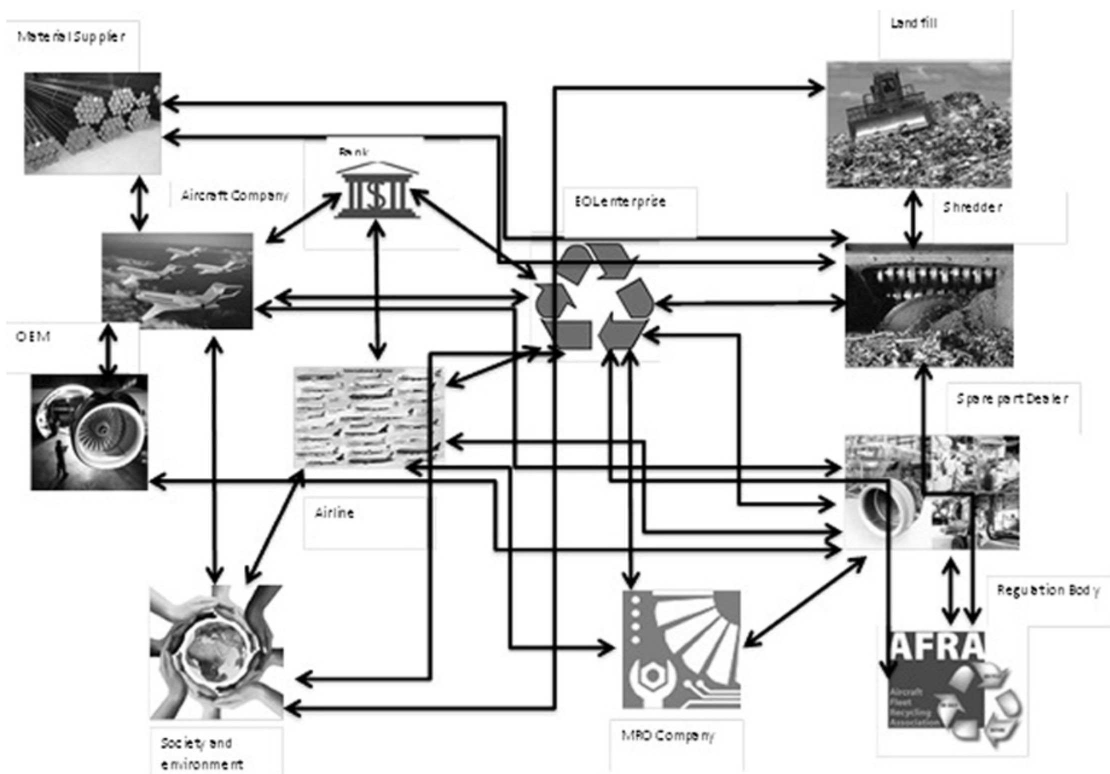


Figure 14 : Stakeholders in EOLARP

Osterwalder & Pigneur (2004) introduced nine building blocks of a business model including value proposition, target customer, distribution channel, relationship, value configuration, core competency, partner network, cost structure and revenue model. For simplification, we defined four aspects of business model in Figure 15. Services reflect the proposed value by project. It's obvious that previous experiences or background of EOL enterprise influence the management approach of the project. For example, an EOL enterprise with background in spares part and services and another one, which is formed to provide EOL aircraft solutions, have not the same approach for dealing with the project.

Regarding value propositions, various services are offered in these projects. Stakeholders address target customers, relationship and distribution channels. With the purpose of extensive perspective of customers we also considered social actors, regulation bodies and market actors. Hence the complexity of relationship, communication mechanism and lobbying with these players are apparent. Designing appropriate risk, revenue and costs model are another challenges in these projects. Costs factors such as skill workers costs, time, transportation costs, investment, required databases such as rates, materials property and capital equipment costs should be considered. Moreover, the revenue items, recovered energy, relationship between costs factors and revenue items, various EOL stakeholders, the type of contracts and agreements are some of elements, which increase the complexity of financial side analysis. Finally, infrastructure includes the core competencies of main player (EOL enterprise), developed processes, and the network of partners should be addressed in business model.

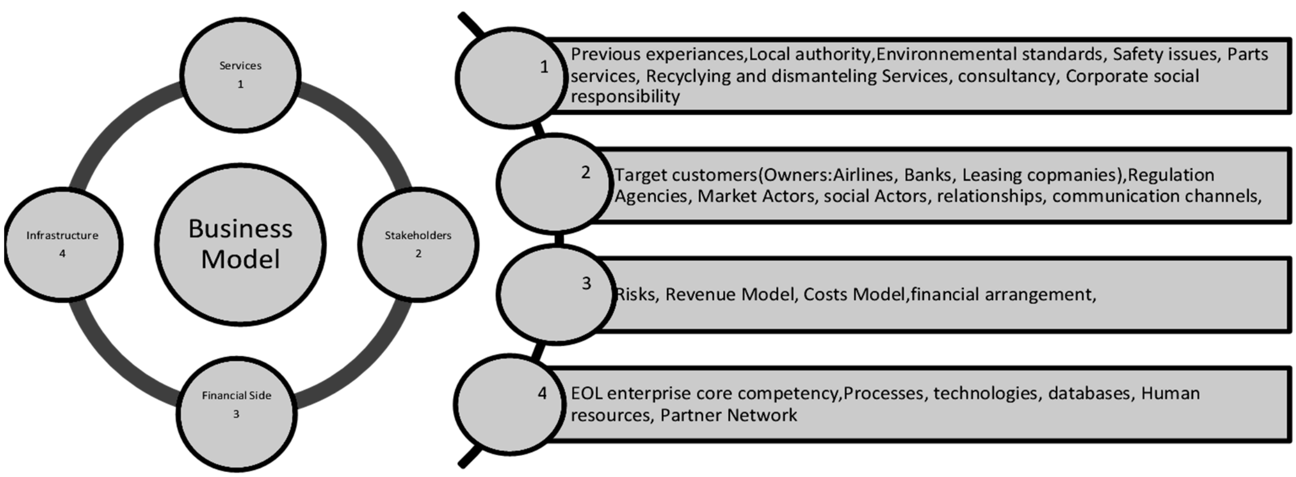


Figure 15 : Typical business model

2.1.7.2. Market and Industry

Used aircrafts, used parts and components markets have the conditions that are challenging. Several internal and external factors are contributed to these challenges. Used aircraft inventories, equipment regulatory in the industry, financing and manufacturing issues are some internal factors. Increasing maintenance costs, outdated avionics equipment, noise compliance issues and parts availability limit operating these aircrafts and they are rapidly becoming economically unfeasible. The external factors include financial crisis, demand for used aircraft especially in India, Middle East, Eastern Europe, and especially Russia, reduced the supply of funds available (Smith, 2010).

The business of treating materials from End-of-Life products is a small slot of overall business of aircraft companies, and it's not feasible to commit reverse supply chain and related treatment channels for this problem. The total weight of aircraft entering the End-of-Life phase is small compared to the weight of other transportation means such as personal vehicles (Eco-Efficiency and Sustainability, p.10).

Considering these issues we can come to this conclusion that applying general green supply chain practices cannot be effective for this purpose. Given these findings, developing new ways in deployment of supply chains of aircraft companies to achieving the operative outcomes is another interesting and challengeable issue. But the structure of supply chain in these companies are complicated and changed over time.

In aerospace supply chain, the large players are supported by a vast supplier base globally and these suppliers are supplied by a large base of tier 2 and tier 3 suppliers, which serve multiple industries (such as industrial manufacturing or automotive). These are followed by tier 3 suppliers, which include suppliers of machined components such as castings and raw materials suppliers for metals and rubber (Tiwari, 2005).

When some of aircraft parts are disposed of, it is important that they are destroyed beyond repair to avoid entering these parts to the market. The component that enters the market without the right documentation or without legal documentation is called a bogus part. From safety perspective, controlling and tracing these parts is critical to avoid the possibility of terrible consequences. The aviation sector follows the global economic trend and when economies slow down also travel by air slows down. And this matter can influence the demand of fleet and subsequently the end of life aircraft market. The role of component dealers, the demand for spare part component is the other factors that influence this market. Maintenance market can also affect the parking rate of aircraft and dismantling and disassembling options (Heerden& Curran, 2010).

Based on these facts, developing a model is needed to address the dynamic behavior of market and various aspects of economics of aircraft recycling.

2.1.7.3. Knowledge Management Framework

The aircraft end of life problem is a new field of study. Therefore, the literature, which addresses the models, optimization tools and techniques in different operational processes in this area, is limited. We addressed the key issues in aircraft end of life problem and gathered some works in this field or other related studies in automotive industry. Table 3 shows the key issues and the references. This simple summary can show the different areas and fields of study in EOLARP.

Table 3 : The different field of studies in EOLARP

No	Key issues in End of life operational process		References
1	Structure for end of life treatment	Infrastructure of collection centers Designing facilities, location, size Networks and key player relationship Inspection Risk assessments identifying and recognizing potential hazard Substances of concerns	Madachy(1996), Paul(2001),ACADEMY-G9- ISSUE 1, Maguad & Jallon (2001), Sendijarevic et al. (2001),Grilc & Fabjan (2003)
2	Collection		
3	Pre-processing		
4	Inspection		
5	Re-using	Quality and reliability assessment Sorting Second hand part market issues Cost and benefits evaluation Maintenance issues	Anityasari & Kaebernick (2008), Maintenance et réparation aéronautique Base de connaissances et évolution (2010), ACADEMY-G9 : ISSUE 1, Kovacs & Haidegger(2006), Bellmannand Khare. (2000)
6	Repair-refurbishing		
7	Disassembly	Process modeling Sequence modeling Automation of process Requirements Proper tools	Lambert(1997), Lambert(2003), Duta et al. (2003), Johnson & Wang (2010), Seo et al. (2001),
8	Material recovery	pre-shred materials-recovery technologies post-shred materials-recovery technologies materials identification technologies technologies for the recycling of specific components Advanced Materials Recycle Technology	Jody et al. (2009), Nissan Green Program 2005,
9	Life cycle analysis	Design modifications for facilitation in disassembly Material selection Design for Environment life cycle cost analysis	Horvath & Chester (2007), Jody et al. (2009), Marx et al. (1995), AeroStrategy Management Consulting Report (2010), Nelson(2010) , Ilg(2006)
10	Design for recycle		
11	Technology	Mechanical Separation Technology Energy Recovery Technology thermochemical conversion technologies Other technologies	Winslow et al. (2004), Russo et al. (2002), Jong et al. (2005), Pomykala et al. (2003), Daniels et al. (2000), Kresta(1999), Fuchs(1999), Automative Materials Recycle Bibliography
12	Environmental/Energy Benefits	Footprint and landfill issues CO_2 emission Use of metal and polymers Energy Savings Energy requirements Of recycling processes	Pomykala et al. (2007), ACADEMY-G9-ISSUE 1
13	Reducing waste	Recognising the cost of waste Design, innovation and technology Sustainable business models	Waste reduction (2007)
14	Response to recycling law or regulation	Relevant regulations Future regulations Customers' requirements	ACADEMY-G9: I SSUE 1, The Aircraft at End of Life Sector: a Preliminary Study
15	Human resources issues	Training Labor costs Health and safety issues	ACADEMY-G9 :ISSUE 1, The Aircraft at End of Life Sector: a Preliminary Study

Brand & Karvonen (2007) presented a concept that clarifies the knowledge characteristics in sustainable development context. The authors introduced four conventional forms of expertise and explained the ecosystem of expertise. In this approach, with the aim of deal with complexity of sustainable development problems we need "Sustainability expert" from a transdisciplinary perspective. They concluded with some advices to preserving the outlook on the whole system, pursuing strategic, transdisciplinary collaborations and preventing the institutional barriers with politicization.

In the other study by Komiyama & Takeuchi (2006) knowledge structuring introduced as an important principal pace in the effort to attain a broad view of sustainability issues. The authors explain the interconnection facet of sustainability problems in addition to complexity and emphasize that clarification of different aspects of these problems is only way to solve them. They believe that developing a platform of knowledge with allowing an outline of the whole network of problems and systematically organizing different fields of analysis provides comprehensive solutions to these problems.

Knowledge communication involves exchanging, sharing, transmitting, and cross-linking knowledge among members of different groups (Heinze, 2003, cited in Chiesa et al., 2009).

Effective Knowledge communication can help EOLARP in access to imperative breakthrough in processes, management practices or relevant technologies of EOL aircraft treatment around the world and this knowledge exchange can facilitate and accelerate the project and target achievements.

The distance between the knowledge units can demonstrate the complexity and diversity of knowledge sharing structures. For example, Figure 16 shows the AFRA members around the world. If we assume this community as a basis for designing knowledge network, it's obvious that different cultural background, specialization, motivation for knowledge exchange, the probability for conflicts (Schüppel, 1996, cited in Chiesa et al.,2009) and lack of effective communication channels may be considered as knowledge sharing barriers and build complexity in knowledge management framework for EOLARP.

Figure 16 : AFRA members around the world: based on information in AFRA official website

Not even in knowledge acquisition from different knowledge sources around the world, but also knowledge sharing mechanism among partners in the project raise some challenges related to diversity of knowledge units and complexity of sharing mechanism.

2.1.8. Performance Measurement Framework

The International Standards Office (ISO) has defined a method for calculating the performance of the recycling of Road Vehicles. However, no model has emerged for measuring performance within the aviation sector (Heerden& Curran, 2010). The ISO approach define recyclability and recoverability rates based on percentage of reused components, recycled materials, recovered energy from material and undefined residue versus vehicle mass. Heerden& Curran (2010) believe that recyclability and recoverability metrics are useful for the aviation sector as end-of-life performance indicators. However, they mention a number of challenges in computing these metrics. For example, the authors explain that when a component is reused, it is in turn replacing another component that needs to be disposed of. Hence this matter should be considered in the model. In addition, the quality of work related to first aircraft of a model is different from the last one. Because in first aircraft of model, all disassembled parts have the potential to be used in other aircraft in the same model which still flying but for last one this is not the case.

Furthermore, these aspects are only related to the operational aspect of EOLARP. It's obvious that the different internal/external pressures and types of metrics should be considered in planning performance measurement system. Health, safety and environment, operation, engineering, accounting and human resources as internal factors and regulation, community and suppliers as external factors should be considered in green context (Hervani et al., 2005). Corporate social responsibility is another aspect, which should be noted in developing performance management system.

As the balanced scorecard (Kaplan & Norton, 1996) is used widely in business and industry and has elements of design, planning and the learning, this methodology can present diversity, complexity and dynamics of performance management in EOLARP. Figure 17 illustrates the measures for aircraft end of life problem in four perspectives of balanced score card method. Some of these metrics have relations with each other and need to be addressed in context of stakeholders' value framework. This matter reflects another sort of challenges for designing a system for performance management.

The perspectives and measures have been derived from literature and the authors' opinions for developing a framework for performance measurement as a prototype for performance measurement in EOLARP. Some of them are new; however, the others are used and combined in different way.

The completed framework including the relevant objectives, targets and initiatives needs participating of industrial experts, which propose as a further study.

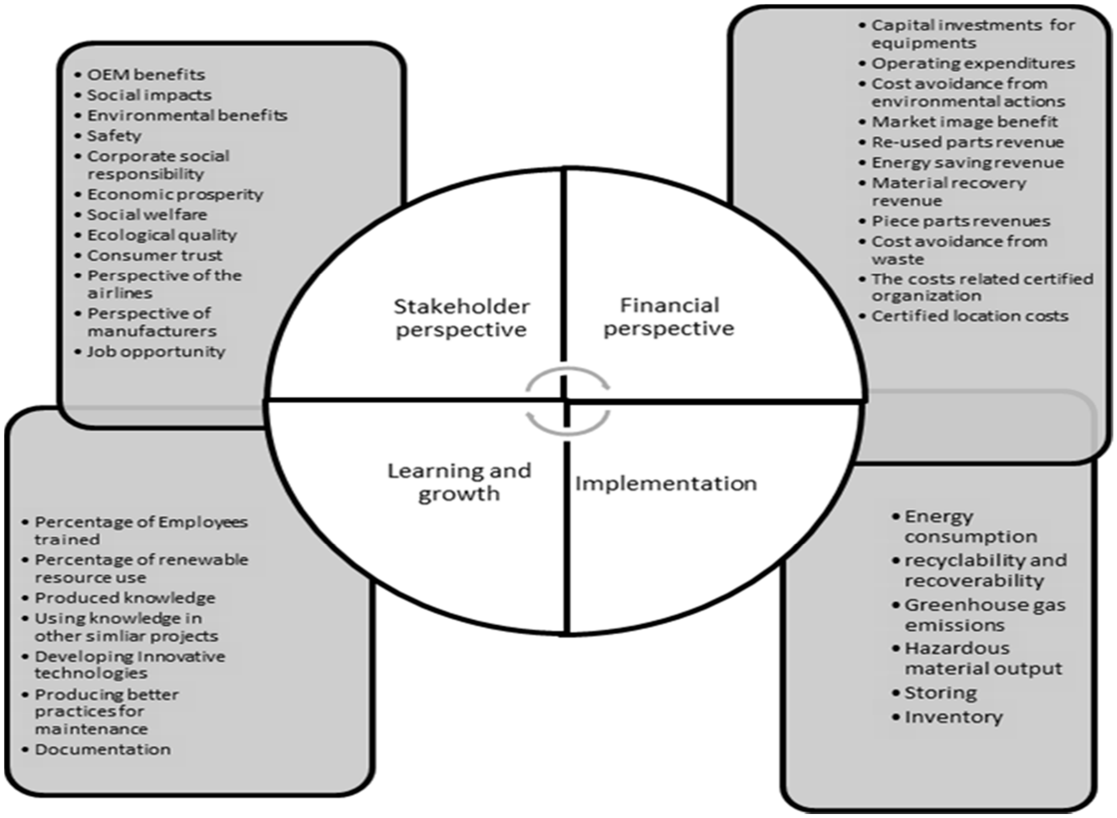


Figure 17 : Basic balanced scorecard framework for performance measurement in EOLARP

2.1.9. Outlook and Opportunities for Future Research

During the recent decade, considering the directives and regulation in automotive industry, several models and solutions are developed for car recycling. Many studies address the management practices, ongoing innovation or limitation of end of life vehicles treatments in different countries and regions.

Several works address reverse logistics with different approaches such as network design and system dynamics.The other studies cover Economic and infrastructure, Shredder Management, Disassembly, Reuse, Recycling, Law and directives and Waste management.In addition, different modeling tools and optimization approaches are applied to end of life operational process. Some of these approaches are shown in Table 4.

Treating materials from End-of-Life products in automotive industry is an important niche in their overall business. Therefore, the designing for reverse logistics and green supply chain can be a motivating choice for manufacturers. In contrast, we face a different, intricate and dynamic context in tackling to the EOL aircraft problem. The reasons are including the absence of relevant directives in aerospace industry, size of treated materials from End-of-Life products, the complexity and challenges in fleet recycling process and potential consequences, the multilayered relationship among partners and players, definition appropriate business model and considering social and environmental aspects.

Table 4 : Modeling, tools and optimization approaches EOL operational process

No	End of life operational process	Modeling , tools and optimization approaches	References
1	Infrastructure for end of life treatment	Bench marking, Best practices, Computer Programs, Heuristics, Collaborative Database, LP and MILP,System Dynamics Modeling, decision Framework, Scenario analysis, Business process reengineering,	Madachy (1996), Paul (2001), (Eco-Efficiency and Sustainability), Maguad & Jallon (2001), Sendijarevic et al. (2001), BloemhofRuwaard (1995), Chouinard et al. (2005), Fleischmann et al.(2000), Giannikos, I. (1998), Hu et al. (2002), Kumar & Yamaoka (2007)
2	Re-using Repair-refurbishing	(Multi) agent-based ICT solutions, Assessment Methodology, cost-benefit analysis, Hierarchical decision model,	Anityasari & Kaebernick (2008), Maintenance et réparation aéronautique Base de connaissances et évolution (2010), (Eco-Efficiency and Sustainability), Kovacs & Haidegger (2006), Feser et al. (2003), Ashayeri et al. (1996), Blumberg, (1999), Ferrer, G. (1997), Guide & Pentico, (2003)
3	Disassembly	Logic network modelling, Case Studies, Integer Programming, Mathematical programming methods, Adaptive planners, Heuristic algorithms, Precedence relations, Methods related to artificial intelligence, Petri nets, Design for life-cycle, The hierarchical tree approach, The reverse logistics approach, Disassembly Technologies and Case Studies	Lambert (1997), Lambert (2003), Duta et al. (2003), Johnson & Wang (2010), Seo et al. (2001), Boothroyd & Alting, (1992), Gungor, & Gupta (1998)
4	Life cycle analysis and Design for recycle	Environmental life cycle assessment, Economic life cycle assessment, Ecological analysis, Dynamic modelling, LP and MILP, Lessons learned	Horvath & Chester (2007), Jody et al. (2009), Marx et al. (1995), Lopes (2010), Nelson (2010), Ilg (2006), Boothroyd & Alting (1992)
5	Reducing waste	Lean, Six sigma, Neural models, Graphical representation, Waste-management-plan	Young & Cabezas (1999), Young & Cabezas (2000), Watts (1999)

With growing the number of useless parked aircrafts, dealing with this problem in a well-organized way is needed. EOLARP is a multidimensional and collaborative framework. Various types of values are extracted from these projects. Strategic approach can aid managers in these projects to achieve effectiveness in addition to the conventional performance efficiency targets in projects. In this work we studied the transdisciplinary concept in EOLARP and with applying this concept and strategic approach we presented a framework for further studies. In Table 5 we provide an outlook for some opportunities and prospects for future research based on proposed conceptual framework in this paper.

Table 5 : Research agenda

	The proposed Model	Research highlights
Business Model	✓ Cost Model ✓ Value chain Model ✓ Logistics Model	✓ Value from owner perspective ✓ The revenue from different categories of parts and components (Serviceable component (after removal), Serviceable component (after shop visit), Salvageable component, Un-salvageable component, Rotable component, Consumable parts, Life-limited components, End-of-life components, Piece parts, Subassembly parts) ✓ The revenue from recovered materials ✓ Developing method for estimation expected market value and market size for these parts or components based on the model, commonality, and different factors, which affect the market value ✓ The main actors in value chain (material and cash flow among actors, level of investment, value added) ✓ Value added operations ✓ EOL processing key decisions ✓ Developing different scenarios based on recovery, recycling or environmental targets and processing key decisions and evaluation method ✓ Inventory challenges ✓ Logistics issues based on the location of parting-out process
Market and Industry	✓ Market behavior Model ✓ or Policy design Model	✓ Analysis of key parameters in behavior of second hand part market, Spare part markets, MRO companies Component dealers, Component brokers and Buying parties ✓ Global and local economy analysis (for example, global fleet growth, Demand for travel, Aircraft being offered on the market, Parked aircraft) ✓ The act of aircraft manufacturers ✓ Developing scenarios based on the above mentioned factors and evaluation of different scenarios
Knowledge management framework	Knowledge network model	✓ Developing an appropriate architecture for knowledge units ✓ Developing different scenarios in knowledge sharing among players ✓ Identifying the key results from knowledge model ✓ Optimization of knowledge sharing among players to achieve the key results
Performance management framework	Strategic performance management Model	✓ Identifying the needs of project in performance evaluation ✓ Identifying the appropriate perspectives ✓ Developing metrics and indicators

References

Ackoff, R. L. (1970). *A concept of Corporate Planning.* New York, NY: Wiley.

Anityasari, M., & Kaebernick, H. (2008). A Generic Methodology to Assess Quality and Reliability in the Reuse Strategy 15th CIRP International Conference on Life Cycle Engineering.

Ansoff, H. I. (1965). *Corporate Strategy.* New York, NY: McGraw Hill.

Ashayeri, J., Heuts, R., & Jansen, A. (1996). Inventory management of repairable service parts for personal computers. *International Journal of Operational and Production Management, 16*, 74-97. http://dx.doi.org/10.1108/01443579610151760

Automotive Materials Recycle Bibliography, Argonne National Laboratory. Retrieved from http://www.es.anl.gov/Energy_systems/CRADA_Team/recycle_bibliography/Recycle Reference2001-31-09webversion.pdf

Bellmann, K., & Khare, A. (2000). Economic issues in recycling end-of-life vehicles. *Technovation, 20*(12), 677-90. http://dx.doi.org/10.1016/S0166-4972(00)00012-2

BloemhofRuwaard, J. M., van Wassenhove, L. N., Hordijk, L., &Beek, P. V. (1995). Interactions between operations research and environmental management. *European Journal of Operational Research, 85*, 229-243. http://dx.doi.org/10.1016/0377-2217(94)00294-M

Blumberg, D. F. (1999). Strategic examination of reverse logistics & repair service requirements, needs, market-size and opportunities. *Journal of Business Logistics, 20*, 141-159.

Boeing 2010 Environment Report. Retrieved from http://www.boeing.com/aboutus/environment/environment_report_10/boeing-2010-environment-report.pdf

Boothroyd, G., & Alting, L. (1992). Design for assembly and disassembly. *Annals of the CIRP, 41*, 625-636. http://dx.doi.org/10.1016/S0007-8506(07)63249-1

Bower, J. (1970). *Managing the Resource Allocation Process: A Study of Corporate Planning and investment.* Harvard business press Boston.

Brand, R., &Karvonen, A. (2007). The ecosystem of expertise: complementary knowledge for sustainable development, Sustainability. *Science, Practice, & Policy, 3*(1), 21-3. Retrieved from http://scholar.google.ca/archives/vol3iss1/0601-004.brand.html

Brown V. et al. (2010). *Tackling wicked problems through the transdisciplinary imagination.* London, UK: Earth scan Ltd.

Buxton, D. et al. (2006). The Aero-Engine Value Chain Under Future Business Environments: Using Agent-Based Simulation To Understand Dynamic Behaviour, MITIP 2006. Retrieved from http://www.anylogic.com/upload/iblock/cf1/cf1fa4baac81b4caa46d81f980b879fd.pdf

Chester, M., & Horvath, A. (2007). *Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas, and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air.* Working Paper UCB-ITS-VWP-2007-7. Retrieved fromhttp://repositories.cdlib.org/its/future_urban_transport/vwp-2008-2/

Chiesa et al. (2009). How Many Brains Does It Take to Build a New Light: Knowledge Management Challenges of a Transdisciplinary Project. *Mind, brain and education, 3*(1), 17-26. http://dx.doi.org/10.1111/j.1751-228X.2008.01049.x

Chouinard, M., D'Amours, S., & Ait-Kadi, D. (2005). Integration of reverse logistics activities within a supply chain information system. *Computers in Industry, 56*, 105-124. http://dx.doi.org/10.1016/j.compind.2004.07.005

Daniels, E. J. et al. (2000). Materials Recovery from Shredder Residues, Proceedings of the Fourth International Symposium on Recycling of Metals and Engineered Materials, Committee of the Extraction & Processing Division and the Light Metals Division of TMS, October 22-25. Retrieved from http://www.osti.gov/energycitations/servlets/purl/759079-jUwiUD/webviewable/759079.pdf

Després, C. Brais, N., &Avellan, S. (2004). Collaborative planning for retrofitting suburbs: transdisciplinarity and inter subjectivity in action. *Futures, 36*(4), 471-486. http://dx.doi.org/10.1016/j.futures.2003.10.004

Duta, L., Filip, F. G., & Henrioud, J. M. (2003). A Method for Dealing with the Multi-Objective Optimisation Problem of Disassembly Processes. *Proceedings of the IEEE, International Symposium on Assembly and Task,* Planning ISATP 2003, Besançon, France.

Eco-Efficiency and Sustainability, G9, ISSUE 1, Process for Advanced Management of End-of-Life of Aircraft, ACADEMY. Retrieved from http://www.airbus.com/company/environment/documentation/?eID=dam_frontend_push&docID=4041

Facanha, C., & Horvath, A. (2007). Evaluation of Life-cycle Air Emission Factors of Freight Transportation. *Environmental Science & Technology, 41*(20), 7138-7144. http://dx.doi.org/10.1021/es070989q

Fensel, D. (2001). *Ontologies: Silver Bullet for Knowledge Management and Electronic Commerce.* Heidelberg: Springer Verlag.

Ferrer, G. (1997). The economics of tire remanufacturing. *Resources, Conservation and Recycling. 19*, 221-255. http://dx.doi.org/10.1016/S0921-3449(96)01181-0

Fleischmann, M., Krikke, H. R., Dekker, R., & Flapper, S. D. P. (2000). A characterization of logistics networks for product recovery. *Omega, 28*, 653-666. http://dx.doi.org/10.1016/S0305-0483(00)00022-0

Freeman, R. E. (1984). *Strategic management: A stakeholder approach.* Boston: Pitman/ Ballinger (Harper Collins).

Freeman, R. E., &McVea, J. A. (2001). *Stakeholder Approach to Strategic Management.* Darden Business School Working Paper No. 01-02. http://dx.doi.org/10.2139/ssrn.263511

Fuchs, R. et al. (1999). Apparatus for treating waste materials, U.S. Patent No 5,879,617.

Giannikos, I. (1998). A multi objective programming model for locating treatment sites and routing hazardous wastes. *European Journal of Operational Research, 104*, 333-342. http://dx.doi.org/10.1016/S0377-2217(97)00188-4

Green sky, aviation and the environment. (2010). Retrieved from http://www.afraassociation.org/NewsDocs/10_GreenSky.pdf

Guide, Jr. V. D. R., & Pentico, D. W. (2003). A hierarchical decision model for re-manufacturing and re-use. International Journal of Logistics. *Research and Applications, 6*, 29-35. http://dx.doi.org/10.1080/1367556031000063040

Gungor, A., & Gupta, S. M. (1998). Disassembly sequence planning for products with defective parts in product recovery. *Computers & Industrial Engineering, 35*, 161-164. http://dx.doi.org/10.1016/S0360-8352(98)00047-3

Heerden, D., & Curran, R. (2010). Value Extraction from End-of-Life Aircraft, Encyclopedia of Aerospace Engineering. *Encyclopedia of Aerospace Engineering.* http://dx.doi.org/ 10.1002/9780470686652.eae355

Heinze, T. (2003). *Kommunikationsmanagement.* Hagen, Germany: FernUniversität Hagen.

Hervani, A. et al. (2005). Performance measurement for green supply chain management. *Benchmarking. An International Journal, 12*(4), 330-353. http://dx.doi.org/10.1108/14635770510609015

Hirsch Hadorn, G. et al. (2007). *Handbook of Transdisciplinary Research.* Springer.

Hu, T. L., Sheu, J. B., & Huang, K. H. (2002). A reverse logistics cost minimization model for the treatment of hazardous wastes. *Transportation Research, Part E: Logistics and Transportation Review, 38*, 457-473. http://dx.doi.org/10.1016/S1366-5545(02)00020-0

Ilg, R. (2006). *Novel Innovative Competitive Effective Tilt Rotor Integrated Project, (NICETRIP) Investment.* Homewood, Illinois: Irwin.

Jody, B. J. et al. (2009). Recycling End-of-Life Vehicles of the Future, Energy Systems Division, Argonne National Laboratory, ANL/ES-C0201801.

Johnson, G., & Scholes, K. (1984). *Exploring Corporate Strategy*. Englewood Cliffs, NJ: Prentice-Hall.

Jong, T. P. R. (2005). The Automation of Automobile Recycling. *Proceedings of the 5th International Automobile Recycling Congress,* Amsterdam, Netherlands.

Klein, J. T. (2004). Prospects for transdisciplinarity. *Futures, 36,* 515-526. http://dx.doi.org/10.1016/j.futures.2003.10.007

Klein, J. T. et al. (2001). *Transdisciplinarity: joint problem solving among science, technology, and society: an effective way for managing complexity.* Berlin: Birkhauser.

Koizumi, H. (1999). A practical approach towards transdisciplinary studies for the 21st century. *Journal of Seizon and Life Sciences, 9*, 5-24.

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: building a new discipline. *Sustainability Science, 1*, 1-6. http://dx.doi.org/10.1007/s11625-006-0007-4

Kovacs, G. L., & Haidegger, G. (2006). Reuse of Automotive Parts and Subassemblies, Mechatroniucs, IEEE International Conference.

Kresta, J. E. et al. (1999). Recycling Process for Cross Member Composite Parts, Recycling Process for Cross Member Composite Parts SAE Paper 1999-01-0665.

Kumar, S., & Yamaoka, T. (2007). System dynamics study of the Japanese automotive industry closed loop supply chain. *Journal of Manufacturing Technology Management, 18*(2), 115-138. http://dx.doi.org/1010.1108/17410380710722854

Lambert, A. J. D. (1997). Optimal disassembly of complex products. *International Journal of Production Research, 35*(9), 2509-2523. http://dx.doi.org/10.1080/002075497194633

Lambert, A. J. D. (2003). Disassembly sequencing: a survey. *International Journal of Production Research, 41*(16). 3721-3759. http://dx.doi.org/10.1080/0020754031000120078

Lawrence, B. (2004). Levels of analysis and the qualitative study of quantitative data. *Multi-Level Issues in Organizational Behavior and Processes, 3,* 231-250. http://dx.doi.org/10.1016/S1475-9144(04)03010-3

Lopes, J. V. O. (2010). *Life Cycle Assessment of the Airbus A330-200 Aircraft.* PhD. Dissertation, Instituto Superior Technico, UniversidadeTecnica de Lisboa.

Madachy, R. J. (1996). System Dynamics Modeling of an Inspection-Based Process. Software Engineering, *Proceedings of the 18th International Conference,* 376-386. http://dx.doi.org/10.1109/ICSE.1996.493432

Maguad, M., & Jallon, F. (2001). *Substances of Concern: A Collaborative Database.* SAE Paper No. 2001-01-3734.

Maintenance et réparation aéronautique Base de connaissances et evolution. (2010). Rapport résume les travaux d'un groupe interministériel piloté par le PIPAME et réalisé par CYBEL.

Marx, W. J. (1995). A Hierarchical Aircraft Life Cycle Cost Analysis Model, the American Institute of Aeronautics and Astronautics.

Max-Neef, M. (2005). Foundations of transdisciplinarity. *Ecological Economics, 53,* 5-16. http://dx.doi.org/10.1016/j.ecolecon.2005.01.014

Michael, J. N., & Charles, M. M. (2007). Published to Oxford Scholarship Online. http://dx.doi.org/10.1093/acprof:oso/9780195172119.001.0001

Morecroft, J. D. (1994). Executive knowledge, models, and learning. In J. D. Morecroft & J. D. Sterman (Eds.), *Modeling for Learning Organizations* (pp. 3-28). Portland: Productivity Press.

Nelson, J. R. (2005). *An Approach to the Life-Cycle Analysis Of Aircraft Turbine Engines.* Institute for Defense Analyses, George Mason University, OR 651.

Nissan Green Program. (2005). Objectives and Results. Retrieved from http://www.nissan-global.com/EN/DOCUMENT/PDF/ENVIRONMENT/GREENPROGRAM/Targets_E.pdf

North, M., &Macal, C. (2007). *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation.* New York, NY: Oxford University Press.

Osterwalder, A. (2005). Clarifying business models: origins, present, and future of the concept. *Communications of AIS, 15,* 1-40. Retrieved from http://aisel.aisnet.org/cais/vol16/iss1/1

Osterwalder, A., & Pigneur Y. (2004). An ontology for e-business models. In W. Currie (Ed.), *Value Creation from E-Business Models.* Butterworth-Heinemann.

Paul, R. (2001). How Prepared are U.S. Dismantlers to Meet the EU Directive for ELV Recycling, SAE Paper No. 2001-01-3744.

Pohl, C., & Hirsch, H., G. (2007). *Principles for Designing Transdisciplinary Research.* Proposed by the Swiss Academies of Arts and Sciences. München: oekomVerlag.

Pohlen, T. L., & Farris, M. T. (1992). Reverse logistics in plastics recycling. *International Journal of Physical Distribution and Logistics Management, 22*(7), 35-47. http://dx.doi.org/10.1108/09600039210022051

Pomykala, J. A. et al. (2003). Separation and Recovery of Thermoplastics from Mixed-Scrap Plastics. *Proceedings of the 9th Annual Global Plastics Environmental Conference,* Society of Plastics Engineers, Detroit, MI.

Rode, C. (2000). *In the Eye of the Beholder, Visual and Verbal Cognitive Capacities in Complex Problem Solving.* Working Paper, Think Tools AG.

Rose, C. M. (2000). *Design For Environment: A Method for Formulating Product End-Of-Life Strategies.* Ph.D. Thesis, Stanford University.

Russo, P., Birat, J. P., Aboussouan, L., Geoffroy, X., Quelier, M., & Backert, S. (1999). Upgrading scrap quality by improving shredder operation. *4th ASM International Conference & Exhibition on the Recycling of Metals*; Vienna; Austria; 17-18 June 1999, pp. 341-351.

Schüppel, J. (1996). *Wissensmanagement: OrganisationalesLernenimSpannungsfeld von Wissen und Lerntheorie.* Wiesbaden , Germany: DeutscherUniversitätsVerlag/Gabler

Sendijarevic, V. et al. (2004). Recent Developments in Shredder Downstream Separation Processes and Recycling Options for Automotive Shredder Residue, Screening Study to Evaluate Shredder Residue Materials, SAE Paper 2004-01-0468.

Seo, K. K., Park, J. H., & Jang, D. S. (2001). Optimal Disassembly Sequence Using Genetic Algorithms Considering Economic and Environmental Aspects. *International Journal of Advanced Management Technology, 18*, 371-380. http://dx.doi.org/10.1007/s001700170061

Shenhar, A. J. (2004). Strategic Project Leadership: Toward a strategic approach to project management. *R&D Management, 34*, 569-578. Retrieved from http://ssrn.com/abstract=610458

Shenhar, A. J., Dvir, D., Levy, O., &Maltz, A. C. (2001). Project Success: A Multidimensional Strategic Concept. *Long Range Planning, 34,* 699-725. http://dx.doi.org/10.1016/S0024-6301(01)00097-8

Shrivastava, P., & Grant, J. H. (1985). Empirically Derived Models of Strategic Decision making Processes Strategic. *Management Journal, 6*, 97-113. http://dx.doi.org/10.1002/smj.4250060202

Siles, C. (2011). Aide à la décision pour la gestion d'un parc d'avions en fin de vie, École Polytechnique De Montréal.

Smith, D. (2010). The market for used aircraft is spring here yet? *Fly corporate magazine,* 40-41. Retrieved fromhttp://www.fly-corporate.com/pdf/The_Market_for_Used_Aircraft.pdf

Somerville, M., & Rapport, D. (2000). *Transdisciplinarity: Re-creating Integrated Knowledge.* Oxford: EOLSS Publishers.

Stefanovic, J., & Shenhar, A. (2007). Why Companies Need to Adopt a Strategic Approach to Project. *Management Technology Management, 11*(2).

The Aircraft at End of Life Sector: a Preliminary Study. (2007). Retrieved from http://users.ox.ac.uk/~pgrant/Airplane end of life.pdf.

Tiwari, M. (2005). A*n Exploration of Supply Chain Management Practices in the Aerospace Industry and in Rolls-Royce.* Master thesis, Massachusetts Institute of Technology.

Ushold, M., & King, M. (1995). Towards a methodology for building ontologies. *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing held in conjunction with IJCAI.*

Waste Reduction. (2008). House of Lords, Science and Technology Committee, 6th Report of Session 2007–08.

Watson, M. (2009). End of Aircraft Life Initiatives, SBAC Aviation and Environment Briefing Papers. Retrieved fromhttp://www.sustainableaviation.co.uk/wp-content/uploads/end-of-aircraft-life-initiatives-briefing-paper-11.pdf

Watts, D. J. (1990). Waste reduction techniques. *Water Environment Technology*. CODEN: WATTE.

Winslow, G., Appel, B., Adams, T., Simon, N. et al. (2005). Recycling Shredder Residue Containing Plastics and Foam Using a Thermal Conversion Process. SAE Technical Paper 2005-01-0848. http://dx.doi.org/10.4271/2005-01-0848

Young & Cabezas. (1999). Designing sustainable processes with simulation: the waste reduction (WAR) algorithm. *Computers and Chemical Engineering, 23,* 477-1491. http://dx.doi.org/10.1016/S0098-1354(99)00306-3

Young, D. et al. (2000). The waste reduction (WAR) algorithm: environmental impacts, energy consumption, and engineering economics. *Waste Management, 20,* 605-615. http://dx.doi.org/10.1016/S0956-053X(00)00047-7

2.2. Toward a Projection model for estimation of End of Life Aircrafts

2.2.1. Résumé

Le traitement des avions retirés compte tenu des impacts environnementaux, sociaux et économiques devient un problème émergent dans l'industrie de l'aviation. L’estimation du volume d'avions en fin de vie (AFV) a un grand impact sur la mise en œuvre des politiques de développement durable et l'adoption de nouvelles réglementations. Dans l’état actuel, il y a peu de recherches effectuées sur la prédiction du nombre de véhicules en fin de vie. Cette étude permet d'examiner les modèles existants, de relever les défis pour l'estimation des avions en fin de vie et propose une approche intégrée pour la prédiction des AFV.

Mots-clés- Avions en fin de vie, modèles de projection, défis

2.2.2. Abstract

Dealing with retired aircrafts considering the environmental, social and economic impacts is becoming an emerging problem in the aviation industry in near future. Estimation of the volume of end-of-life aircrafts (ELAs) has a great impact on the implementing of the sustainable policies and passing new regulations. There is few research carried out about the prediction of the number of End of life vehicles. This study, with reviewing the existing models, addresses the challenges for estimation of retired aircrafts and proposes an integrated approach for prediction of ELAs.

Keywords—End of life Aircraft, Projection models, Challenges

2.2.3. Introduction

In the coming years considering the expected increase in retirements of fleet, aviation industry faces a new problem. The rising cost of fuel must also be taken into account, since this factor could force the owners to withdraw aircrafts from services because they are unable to financially support the operating of aircraft with intensive fuel consumption. Fortunately, aircraft owners (rental companies, airlines, banks, part brokers, individuals, etc.) are increasingly environmentally conscious [1]. The green image associated with treatment of aircrafts at the end of life based on environmental concerns moved gradually as a criterion of competitiveness on the global market [2]. At this time, an aircraft is withdrawn from services before the end of its operational life in order to reduce operating costs and the replacing it with a more efficient aircraft [3]. The sustainable policies regarding whole aircraft life cycle aims to minimize the waste and improves the technologies for material recovering, recycling and parts refurbishing and remanufacturing. Until now, there is not any particular legislation applicable for ELAs but in future considering the increasing number of retired fleet, the attention of governments and aviation authorities will be increased. Estimation of the volume of end-of-life aircrafts (ELAs) has a great impact on the implementing of the sustainable policies and passing new regulations. Some studies proposed estimation methods for the End of life Vehicles (ELVs) using grey theory [4], combination of historical data on population, the number of cars per capita (car density), GDP per capita and the vintage distribution of cars [5], multiple linear regressions, neural networks and optimized neural network based on genetic algorithm [6] and vehicle use life distribution [7]. To the best of our knowledge, only one study considered prediction model for ELAs to answer the question of how many aircraft will be withdrawn from service and will not return to operation [8]. This study used normal distribution and fitted this distribution with the accessible data of the aircraft. Hence, this paper aims to address the influential factors influencing the ELAs volume and the challenges for proposing a holistic prediction model which integrates multiple factors. This paper is organized as follows: section 2.2.2 provides an overview of forecasting in aviation industry. Section 2.2.3 presents the different prediction models for ELVs. Section 2.2.4

illustrates the proposed approach for estimation of ELAs and finally section 2.2.5 concludes with some remarks and proposes the direction for future research.

2.2.4. Overview of forecasting in aviation industry

Different companies and organizations provide market outlook in aviation industry. Boeing and Airbus publish two important sources of forecast. Rolls-Royce is also a main source of industry forecasts. Airport council international (ACI) and The International Air Transport Association (IATA) are the other association which provide market forecast in the industry. There are several factors influencing the global forecast trends. For Boeing, industry indicators, including fuel, market liberalization, airline capabilities, airline strategies, emerging markets, economic growth, high-speed rail, and the environment are considered in the current market outlook estimations [9]. For Airbus, the global market forecasts contains three steps: the traffic forecasts which provides outline related to traffic growth, network forecasts which give the growth in the airline networks and demand forecasts which estimates the required fleet for covering such demand [10]. Study of the methods applied by different players reveals that three essential inputs contribute for global trend forecasts. First, the demand input which is obtained by market and socio economic data. Second, the traffic input which is attained by historical trends, airline strategies, traffic databases and industry indicators. And third, the company's strategy which is influenced by its vison, assumptions, marketing plan and geographical concentration in the market.

The number of aircrafts that need to be replaced or withdrawn from services usually is a part of these reports. However, there are substantial differences between these perdition resources [8]. When we want to assess the business cases in ELAs context or consider the sustainability of its potential recycling infrastructure in the future, identifying an accurate estimation is essential. Table 6 shows the difference between Boeing and Airbus prediction according to current market Outlook (2013-2032) of Boeing and Global market forecast of Airbus (2013-2032) [10-11].

Table 6 : Retired aircrafts based on Boeing and Airbus forecast

Prediction	Passenger fleet in 2032	Freighter fleet in 2032	Retired Passenger fleet by 2032	Retired Freighter fleet by 2032	Total retired fleet by 2032
Boeing	38,430	2,810	14,580	1,220	15,800
Airbus	28,355	2,730	8,939	1,359	10,334

In spite of wide areas of similarity in the utilized approaches by main players of forecasts of future demand of commercial aircraft (Airbus, Boeing, Rolls-Royce and AVITAS), there are significant areas of divergence that comes from the methods and assumption of these estimations [12]. The author believes that the assumption of retirement rate and fleet renewal are different among these players. He analyzed the Boeing and Airbus forecasts cover the period 1998-2018, Rolls-Royce for 1997-2017 and AVITAS from 1999-2019. Based on this reference, the average age of fleet replacement is estimated at 24 years (20 years for Asia and Pacific and 29 years for Latin America) for Airbus , for Boeing, 25 years for (single aisle) , 28 years (twin-aisle) and 35 years for freighters. Rolls-Royce uses a gradually flattening curve with a peak (23.5 years) to show the average of the removal of the fleet from the airlines and AVITAS with normal distribution overestimated the retirement rate. AVITAS made this assumption that for any certain aircraft type of a vintage year, retirements for those aircraft are dispersed over several years around an average mean age [12: p.9].

There are some important issues which need to be taken into account in order to predict the amount of ELAs. First of all, for accurate evaluation, the yearly retirement rate and the information based on the type of the aircraft are crucial [8]. For business models the information per region is also important. Hence, In addition to forecasts reports at hand, developing a holistic approach for an accurate prediction is valuable and required in future.

2.2.5. The prediction models and applicability for ELAS

In this section, the different prediction models with their applications in ELVs (if any) are introduced and their pertinences in the case of ELAs are analyzed and discussed. For each model, there are advantages and drawbacks which should be considered. It seems that an integrated approach with combination of several methods needs to be used in the estimation of the volume of ELAs to sustain the accuracy of the results.

2.2.5.1. Normal distributions

A simple approach for estimation of the number of ELAs is normal distribution. The scrapping age can be assumed as a normal distribution and fit this distribution with the existing data of the aircraft [8]. There are two parameters in normal distribution (Eq.2.2.1); μ and σ, which are estimated based on the available data.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \qquad (2.2.1)$$

AVITAS also used this approach for estimation of the aircraft retirement rate [12]. The application of the model is easy and the sources of data are already existed. However, there are some limitations for using this method. First of all, the data related to scraped aircrafts do not cover the fleet, which are parked or stored and already reached to their EOL. Moreover, the data for all regions and countries are not available.

2.2.5.2. Multiple linear regression model

As there are different factors affecting the ELAs count, this method is an easily applied prediction model. Multiple regression model is formulated as Eq.2.2.2. Where γ is dependent variable and y_1,y_2,…and y_n are the influential factors or independent variables. The coefficient will be estimated based on the dependent and independent variables.

$$\gamma = \alpha_0 + \alpha_1 y_1 + \alpha_2 y_2 + ... + \alpha_n y_n \qquad (2.2.2)$$

Guangdong et al. used this approach to predict the number of ELVs in China [6]. They considered seven factors: production volume, sale volume, vehicle population, highway freight turnover, passenger turnover, GDP and income of per urban resident as independent variables of the regression model. For ELAs estimation, we have also several influential factors such as fuel price, airline business models, replacement plans, the value of the aircraft, and the market for the components and so on. But the large list of contributed factors and their relationship make the modeling task more difficult. Furthermore, the assumption of linearity is not entirely correct and doesn't lead to consistent results.

2.2.5.3. Modeling based on vehicle's life distribution

Combination of historical and socio economic data as well as car's life distribution are also used in the ELVs context. The authors in study [5] applied historical data on population;

the number of cars per capita (car density), GDP per capita and the vintage distribution of cars in order to develop a projection model for ELVs in EU. For the car's life distribution, they used a Weibull distribution which its parameters adjusted using historical data, mainly from Eurostat. The other study assumed the volumes of ELVs as a function of the year of production and for the years of dismantling and used Weibull distribution function for the division of cars returning at a particular scrapping year [7]. For ELAs, estimation of aircraft's life distribution is a challenging issue. For the complex structure, studying the residual life should be carried out based on different modules and components. There are several approaches which address this problem [13-15]. However, estimation of the life time for aircraft structure or engine may be different. Hence, the question is: which distribution function or model is appropriate for estimation of aircraft's lifetime? The answer needs to be addressed in separate study. It should be noted that, in the complex systems, the failure rate of the whole system depends on structure of the system and the failure rate of each component. For example, in a system consists of a series of different component i, i=1, 2,…, n, the failure rate of the system λ(t) will be as follows:

$$\lambda_s(t) = \sum_{i=1}^{n} \{\lambda_i(t)\} \tag{2.2.3}$$

For simplicity of the calculation, the failure rate of the system can be written as follows:

$$\psi(t) = Max \frac{\lambda_i(t)}{\sum_{i=1}^{n} \lambda_i(t)} \tag{2.2.4}$$

No matter that what is the failure rate function of each component (Constant, Weibull, Exponential, Normal, etc.); the failure rate of the whole system will be constant.

For the aircraft, usually structure is the main element in estimation of the lifetime.

2.2.5.4. Neural networks model

A neural network is a smart computer system that simulators the processing abilities of the human brain [16]. Considering the capability of neural networks for linking the inputs to outputs and data processing , it is widely used in classification, simulation or codification problems [17]. Moreover, the pattern recognition capacity of a neural network provides a good alternative in order to be used as a forecasting tool in business application [18]. Neural network can also handle the non-linearity of samples in the training set [19]. The diagram of neural network model is shown in Figure 18. There are three layers in this approach; neuron input (the independent variables of the model), the hidden layer and the output layer (dependent variable). The algorithm starts with initializing these layers and weighting vector. Then, the output of hidden layers and the output layer are calculated and the weight will be adjusted. The third step is evaluating the error or training performance, if it is satisfied the algorithm will stop otherwise goes to second step and continues the process.

Guangdong, et al., used sigmoid transfer function with seven input neurons in a three layers of neural network structure for estimation of ELVs volume [6]. They also applied genetic algorithm in their study to optimize weights and thresholds of neural network to improve its performance. Although, neural network offers several benefits for prediction, there are some disadvantages for applying this method in the case of ELAs. The black box nature of this method [20] doesn’t allow finding the causal relationships in the model clearly and sensitivity analysis precisely. Since, selecting the input neurons as the influential factors of the model is essential in this approach; model developers should identify the industry context in order to perform the selection process accurately. The weight of criteria and result interpretation needs an expert team to lead to reliable outcomes.

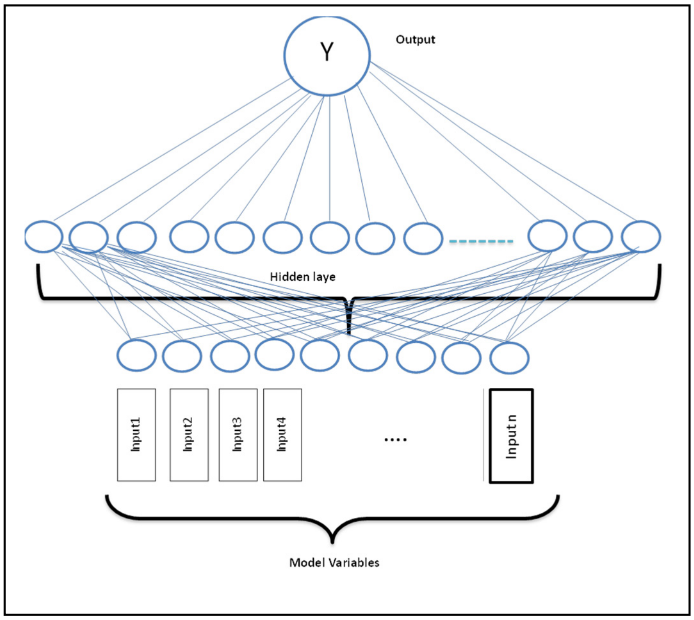


Figure 18 : The neural network model diagram

2.2.5.5. Adaptive Neuro-Fuzzy Interface System (ANFIS)

ANFIS integrates neural networks and fuzzy logic to capture the benefits of both in a unique approach [21]. It consists of a set of fuzzy if–then rules that have learning ability to estimate nonlinear functions. Figure 19 shows an ANFIS structure with two inputs (x, y) and one output f. Based on Takagi-Sugeno fuzzy model [29], two fuzzy if-then rules are as follows:

Rule 1: If x is A1 and y is B1, then

$$f1 = p1x + q1y + r1 \qquad (2.2.5)$$

Rule 2: If x is A2 and y is B2, then

$$f2 = p2x + q2y + r2 \qquad (2.2.6)$$

Where A, B are fuzzy set that their membership functions demonstrate the degree to which the given input satisfies the quantifier. Five layers shown in Figure 19 illustrate the algorithm. In the first layer, the fuzzification process is performed. Usually Bell function is used as membership function. The second layer calculates the fuzzy AND rule and the membership function will be normalized in layer 3. The forth layer performs the following part of fuzzy rule and finally; the output (Eq.2.2.7) will be resulted by summing up the outputs in the previous layer [30- 31].

$$f = \frac{w1f1 + w2f2}{w1 + w2} = \overline{w1}f1 + \overline{w2}f2 \qquad (2.2.7)$$

There are several studies which applied ANFIS for forecasting in business cases [22-24]. As there is some qualitative information or subjective terms in the real life problem, ANFIS can overcome the drawbacks of neural networks with applying a fuzzy interface system [25]. In estimation of the number of ELAs, there are some variables which are subjective and completely related to individual judgment for evaluation. For example, the strength of crisis in the air freight market, the economic and financial environment impacts are the parameters that cannot be quantified precisely. ANFIS with its capability for incorporating fuzzy interface system can remedy the limitation of the neural network for modeling these parameters. However, for accuracy, ANFIS needs a huge data that in the case of ELAs is challenging, especially for a region under study.

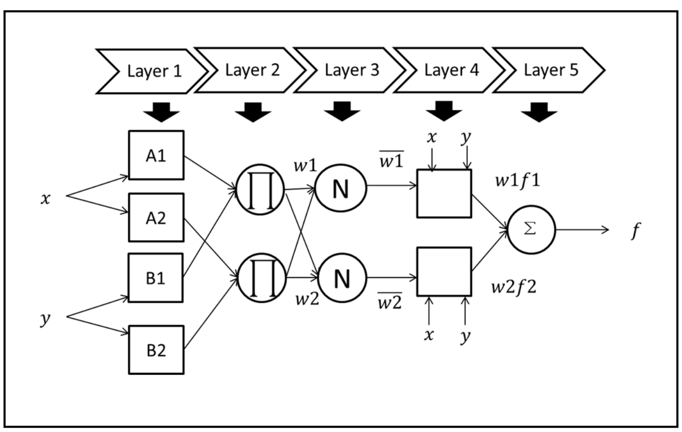


Figure 19 : The ANFIS architecture

2.2.5.6. System dynamics

System dynamics models can offer more consistent forecasts of short- to mid-term trends than statistical models [26]. Moreover, studying the behavior of industry and the changes in its structure can be attained by applying system dynamic. It can aid decision makers with reasonable scenarios in order to achieve the best policies. Lyneis developed system dynamics models for the analysis of the commercial jet aircraft industry and provided justifications to support the capability of this approach in comparison to the one time series or regression/econometric models [26]. As the number of ELVs generated in the market is an essential factor which can impact the robustness of the automobile recycling ecosystem, the "aging sector" usually considered in the models. System dynamic is used for modeling the dynamics of automobile recycling in US [27]. In this study, the aging sector represents the car usage part. The cars after selling enter to the chain of aging until to be retired. In this model, the retirement fraction is kept constant. However, the author explained that income per capita, consumer preferences and driving behavior can dynamically change the retirement rate of the automobiles which are excluded from the model. The ability of system dynamics for analyzing of the causal relationship among the parameters and addressing the dynamic behavior of the aviation market made it a promised approach for ELAs count estimation. Figure 20 shows an example of applying the principles of the system dynamic. The need for a team of experts (with multidisciplinary skills), the required time for modeling, incomplete data, consistency of generated scenarios and the randomness based on non-linear feedback loops [28] are some limitation of applying this approach .

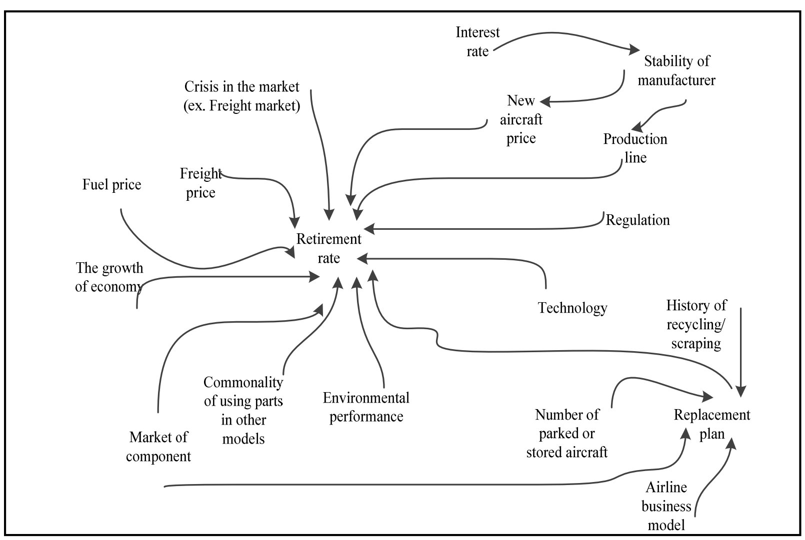


Figure 20 : An example of mapping the influential factors and their dynamics for ELAs

2.2.6. The proposed approach for projection model

Based on the synthesis provided in the previous section, there are some essential requirements for a reliable forecasting model. These requirements are shown in the Figure 21.

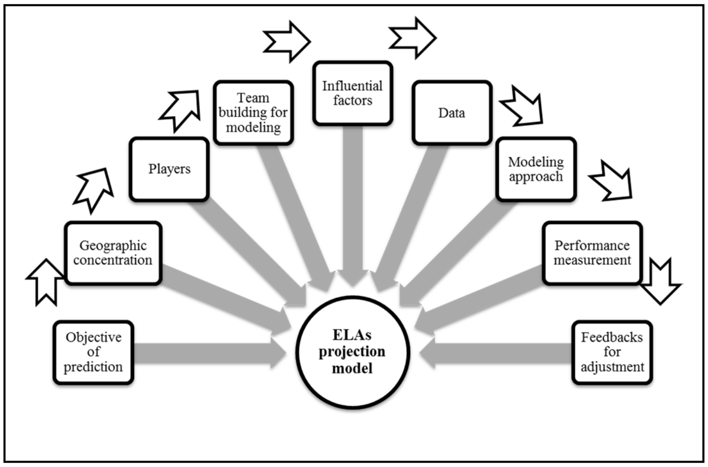


Figure 21 : Requirements for ELAs projection model

The details of each step are presented in the following sub-sections.

2.2.6.1. Objective of prediction & Geographic concentration

There are two main drivers for estimation of ELAs volume. The first one is economic purpose and the second one is environmental purpose. Evaluating a business model for an airline or aircraft owner in order to assess the opportunity of counting ELA in product range of engineering and maintenance department [8] is the objective that needs more accurate estimation of the number of ELAs. In this case, the type of the aircraft and the yearly volume are important information. The geographic concentration is usually limited to the airline business areas. Until now, the dedicated infrastructure for recycling ELAs is limited, however; assessing the economic sustainability of these infrastructures also needs the estimation of the ELAs accurately. The geographic focus is a country or a special region for initiating business plan. The international and regional directives intend limiting the use of hazardous substances in aircrafts (REACH: Registration, Evaluation, Authorization and Restriction of Chemicals) and establish particular objectives on the reuse, recycling and recovery waste from aircrafts (such as EU ELV directive). The projection model for ELAs aids to estimate the environmental effects of wastes generated from these retired aircrafts.

The detailed data on the composition of aircraft material and the ways for reusing recycling and recovering are also required to elaborate the estimation of environmental impacts. In this case, countries for establishing governmental policies or unions are usually taken into account as a geographic boundary.

2.2.6.2. Players and Team building for modeling

Different industrial players need to be considered in developing ELAs projection model. Manufacturers and principle suppliers, airlines, leasing companies, regulation bodies, passengers which also formed the structure of industry as a supply chain [26] are main actors. Considering the interdisciplinary nature of the problem, a team of experts need to be established. The interviews with key players should be conducted. The presentations should be offered to identify the purpose of the modeling and the type of the required data and the roles of people's involvement. Several workshops need to be coordinated to perform the modeling task with participating of the modeler/facilitator and the representatives from key industrial players.

2.2.6.3. Influential factors, Data and Modeling approah

One of the essential steps of the modelling process is identifying the influential factors and mapping their relationships in order to provide the right choice of the modeling approach. The discussions among practitioners and participants through workshops can explore the main factors and its representation. Based on the final factors extracted from workshops, the sources of data should be identified. The historical data and the forecasting reports of the main industrial players are the main sources of the data. However, with respect to the final list of influential factors, the other resources such as airline's database, regional statistical data base and expert's opinions in the case of qualitative parameters should be considered. Based on the number of parameters, the dynamics of the problem, the outcomes of the workshops and the limitation in accessibility of some data, the prediction model will be selected. As discussed in the previous section, the ANFIS and system dynamics are appropriate prediction models considering the complexity of the ELAs problem.

2.2.6.4. Performance measurement and Feedbacks for adjustment

In this step, the results of prediction model should be saved if deemed satisfying. If the results are unfitting, we return to previous steps (e.g. reviewing the parameters) in order to attain satisfying results. There are different performances indicators which can be used to evaluate the consistency of the results. For example, mean value of absolute error, standard deviation of absolute error or correlation coefficient between the actual value and the prediction are used by [6] in order to compare the performance of three prediction models for estimation of ELVs volume in China.

2.2.7. Conclusion

Dealing with retired aircrafts considering the environmental, social and economic impacts is becoming an emerging problem in the aviation industry in near future. Estimation of the number of ELAs, which generated each year, aids decision makers to set appropriate policies in order to manage the resulted waste and environmental impacts. This paper reviewed the different approaches for prediction of the ELAs volume considering the challenges existed in the problem context. An integrated approach is proposed to provide a reliable methodology for estimation of retired fleet. This study has taken a step in the direction of ELA as a new problem of aviation industry and highlighted some guidance points toward a projection model. The future work is to develop a case study based on the proposed framework to illuminate the capability of a systematic approach for estimation of ELAs count.

References

[1] S. Keivanpour, C. Mascle, , & D. Ait Kadi, A Conceptual Framework for Value Chain Analysis of End of Life Aircraft Treatment in the Context of Sustainable Development (No. 2014-01-2232). SAE Technical Paper, 2014.

[2] C. Siles, Aide à la décision pour la gestion d'un parc d'avions en fin de vie (Master dissertation, École Polytechnique de Montréal), 2011.

[3] D. Sainte-Beuve, Évaluation de différentes stratégies de démantèlement de la carcasse d'un avion (Master dissertation, École Polytechnique de Montréal), 2012.

[4] P. Zhao, and T. Lei, "Prediction of the volume of Elvs based on grey system theory," Journal of Industrial Technological Economics, vol. 4, , 2011, pp. 31-35,

[5] F. M. Andersen, H. V. Larsen, and M. Skovgaard, "A European model for the volume of ELVs," International Journal of Automotive Technology and Management, vol. 7, 2008,pp. 343-355,

[6] Tian, Guangdong, et al. "Prediction models of the number of end-of-life vehicles in China." Advanced Mechatronic Systems (ICAMechS), 2013 International Conference on. IEEE, 2013.

[7] Van Schaik, M. A. Reuter, U. M. J. Boin, and W. L. Dalmijn, "Dynamic modelling and optimisation of the resource cycle of passenger vehicles," Minerals Engineering, vol. 15, 2002, pp. 1001-1016

[8] D. J .,Van Heerden, , End-of-Life Aircraft :How to deal with an old aircraft withdrawn from service, Master dissertation,Unpublished,2005.

[9] http://www.boeing.com/boeing/commercial/cmo/forecast_indicators.page

[10] Airbus, Global Market Forecast 2013-2032 , http://www.airbus.com/company/market/forecast/

[11] Boeing –Current market oulook, 2013-2032, http://www.boeing.com/assets/pdf/commercial/cmo/pdf/Boeing_Current_Market_Outlook_2013.pdf

[12] R. Anker, "Comparison of Airbus, Boeing, Rolls-Royce and AVITAS Market Forecasts." Air & Space Europe 2.3 (2000): 4-9.

[13] W.Wang, , & W. Zhang, A model to predict the residual life of aircraft engines based upon oil analysis data. Naval Research Logistics (NRL), 52(3), 2005. 276-284.

[14] T. A.Cruse, & P. M. Besuner,. Residual life prediction for surface cracks in complex structural details. Journal of Aircraft, 12(4), 1975,369-375.

[15] W. Wang, , & W. Zhang,An asset residual life prediction model based on expert judgments. European Journal of operational research, 188(2), 2008. 496-505.

[16] R. Law, , and A.Norman. "A neural network model to forecast Japanese demand for travel to Hong Kong." Tourism Management 20.1. 1999: 89-97.

[17] R. SIMONS, (ed.). Operations Management: A Modern Approach. CRC Press, 2011.

[18] D.C. Pattie and S. John. "Using a neural network to forecast visitor behavior." Annals of Tourism Research 23.1 1996: 151-164.

[19] Wang, Q., & Sun, X, Enhanced artifcial neural network model for Chinese economic forecasting. Proceedings of the International Conference on Management Science and the Economic Development of China. (Vol. 1, 1996, pp. 30-36).

[20] J. V. Tu, Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes. Journal of clinical epidemiology, 49(11), 1996. 1225-1231.

[21] S.M. Jang,– Neuro-Fuzzy and Soft Computing – Prentice Hall, 1997, pp 335–368

[22] M. A.Boyacioglu, & D. Avci, An adaptive network-based fuzzy inference system (ANFIS) for the prediction of stock market return: the case of the Istanbul stock exchange. Expert Systems with Applications, 37(12), 2010,7908-7912.

[23] Yun, Z., Quan, Z., Caixin, S., Shaolan, L., Yuming, L., & Yang, S. (2008). RBF neural network and ANFIS-based short-term load forecasting approach in real-time price environment. Power Systems, IEEE Transactions on, 23(3), 853-858.

[24] G. S. Atsalakis, & K. P. Valavanis,. Forecasting stock market short-term trends using a neuro-fuzzy based methodology. Expert Systems with Applications, 36(7), 2009,10696-10707.

[25] R. J.Li, , & Z. B. Xiong,. Forecasting stock market with fuzzy neural networks. In Machine Learning and Cybernetics, 2005. Proceedings of 2005 International Conference on (Vol. 6, 2005,pp. 3475-3479). IEEE.

[26] J. M. Lyneis,. System dynamics for market forecasting and structural analysis. System Dynamics Review, 16(1), 2000,3-25.

[27] P. Zamudio-Ramirez, .Economics of automobile recycling (Master dissertation, Massachusetts Institute of Technology), 1996.

[28] D. DeTombe, , & J. Harm't Hart, Using system dynamic modelling techniques for constructing scenarios of societal problems. Analyzing Societal Problems, 1996, 57-75.

[29] M.Sugeno, , Industrial applications of fuzzy control, Elsevier Science Pub. Co., 1985.

[30] F.A. Alturki, A.B. Abdennour, Neuro-fuzzy control of a steam boiler turbine unit, Proceeding of the 1999 IEEE, International Conference on Control Applications, 1999, pp. 1050-1055.

[31] S.H. Kim, Y.H. Kim, K.B. Sim, H.T. Jeon, On developing an adaptive neural-fuzzy control system, Proceeding of IEEE/RSJ Conference on Intelligent Robots and Systems, 1993, pp. 950-957.

[32] S. M. Odeh, Using an Adaptive Neuro-Fuzzy Inference System(AnFis) Algorithm for Automatic Diagnosis of Skin Cancer. Journal of Communication and Computer, 8(9), 2011, 751-755.

3. Chapter Three

Decision Making & Dynamics in ELV recycling VC

This chapter is dedicated to the following articles:

“Modeling Robustness of Business Ecosystem of End of Life Vehicles Players” published in Journal of Sustainable Development Studies, 4(1).1-35, 2013

“Economic Sustainability of End-of- Life vehicle recycling infrastructure under uncertainty (A fuzzy logic approach)” published in the Proceedings of International Conference on Industrial Engineering and Systems Management IESM’2013 RABAT – MOROCCO, (pp. 1-6). IEEE

The titles, figures and mathematical formulations have been revised to the keep the consistency through the thesis.

3.1. Modeling Robustness of Business Ecosystem of End of Life Vehicles Players

3.1.1. Résumé

L’infrastructure de recyclage des véhicules en fin de vie (VFV) est un écosystème d'affaires de joueurs semblable à un écosystème biologique. La viabilité de cette infrastructure dépend des interactions entre les parties prenantes. Pour l'évaluation de la robustesse de cet écosystème on doit prendre en considération, non seulement la viabilité économique de joueurs mais aussi les impacts environnementaux et sociaux. En outre, cette évaluation devrait impliquer les forces du marché, l'impact des politiques gouvernementales, les besoins de la société ainsi que l’évolution de la technologie. Dans cette étude, nous avons introduit un cadre de travail pour la modélisation de la robustesse de l'écosystème d'affaires des parties prenantes dans le contexte de recyclage d’automobiles. Ce cadre prend en compte : la réponse aux effets dynamiques, à la stabilité et aux résultats d'apprentissage. Le modèle a été développé pour la modélisation des infrastructures pour le recyclage d’automobiles aux USA. L’architecture du modèle mis au point, pourrait être exploitée dans d’autres contextes.

Mots-clés: écosystème d'affaires, infrastructure VLE de recyclage, forces du marché, politique du gouvernement, marché de la technologie, robustesse.

3.1.2. Abstract

End of life vehicles (ELVs) recycling infrastructure is a business ecosystem of players that similar to a biological ecosystem, the sustainability of this structure depends on the interaction among players. For evaluation, the robustness of this ecosystem, not only economic sustainability of players but also the environmental and social impacts of their strategies should be considered. Moreover, this assessment should involve market forces, the impact of government policies and society needs as well as technology market. In this study, we introduced a framework for modelling robustness of the business ecosystem of automobile recycling players considering the response to dynamical effects, stability and learning outcomes. The descriptions of building blocks of the model are adapted for modelling the car passenger recycling infrastructure in US; however, the architecture of the model can be used in other regions or even in other industries.

Keyword: Business ecosystem, ELVs recycling infrastructure, Market forces, Government policy, Technology market, Robustness

3.1.3. Introduction

Currently, 95% of all the vehicles discarded in the U.S. enter the recovery infrastructure (Kumar & Sutherland, 2009). According to the EPA (US Environmental Protection Agency), 95% of all automobiles in US are plausible to be recycled. There are several players such as automakers, government, recycling enterprises and research centers involved in the automobile recycling chain. The players interdependency, the complex interaction among players, long-term outcome of decisions made by players on the recycling infrastructure, the impact of strategic changes of one entity on the other players and need to adaptation facing to external forces make this network of players as a business ecosystem. The robustness of this ecosystem to survive in response to environment changes requires a systematic approach to studying the behavior of players, planning future scenarios and monitoring the sustainability of players in coming alternatives. This paper proposes a framework for modeling the business ecosystem of automobile recycling in US. The main contributions of this study are listed below:

1. to introduce the recycling infrastructure of automobile as a business ecosystem with comparing the characteristics of the business ecosystem and the nature of recovery infrastructure
2. to propose a modeling approach in order to assess the robustness of this business ecosystem

This paper is structured as follows. Section two includes a brief literature review on automobile recycling in USA and related key studies. Section three introduces automobile recycling infrastructure as a business ecosystem of players. Section four describes the players and the interaction among them. Section five introduces essentials of the model. Finally, section six provides conclusive remarks and areas for further research.

3.1.4. Literature

In addition to different references used in this study, we focused on some key works which explained the different aspects of automobile recycling in USA. In the next parts, we described highlights in this literature and the existing gap in order to introduce the research question.

3.1.4.1. Automobile recycling in USA

After experiencing a period of crisis in the automobile industry in US, this industry will return to their high pre-crisis levels. Heymann (2012) believes that in the longer term, an even higher sales volume is plausible. The author mentions the growing population figures (another 50 million people by 2030) and the importance of cars for US consumers as the main drivers for this growth rate. Vehicles affect the environment over their entire life cycle. Some of these effects occur at the end of their lives such as hazardous substance emissions, and disposals (Kanari et al., 2003). Addressing the environmental issues for ELVs raises a number of serious challenges for the industry. In the USA, there is no explicit legislation regarding the management of ELVs. With respect to the broad landfill spaces with lower costs of waste disposal and lack of standard waste legislation for whole states, recycling industry has received much less interest (Konz, 2009). Automotive industry has an important role in the recycling industries in US and auto manufacturers participate in the programs for improvement recycling management process. For example, Ford has purchased more than 25 vehicle recycling operations in the US, with more expected and has an experimental dismantling center in Germany (Staudinger and Keoleian, 2001). In the absence of the identical legislation in auto recycling, automotive OEMs follow different strategies in a variety range from changes in design to issue a guideline or standards. Each of these strategies has also different impacts on the other players and even can change the economic sustainability (Kumar & Sutherland, 2008) of ELVs business. In USA, the infrastructure related to the recovery and recycling of ELVs is more or less profit driven. The players in this business such as dismantlers or shredders should be gainful to stay in this business (Kumar & Sutherland, 2008). All above mentioned reasons make the infrastructure of recycling ELVs in USA, an attractive area for assessing the business and economic issues, the games between players and the challenges facing the key decision makers.

3.1.4.2. Highlights in literature

The government policies regarding addressing different phases of ELVs recycling process especially those in improving recycling rate can affect new technologies, market share of automotive manufacturers, the profit of dismantlers and shredders and even the sustainability of the overall business. Hence, the first paper is a study by (Konz, 2009), which surveys the existing ELVs directives in US and European Union and propose a framework for the future direction of government policies considering the advantages and disadvantages of EU directives. The second study is a report of the Center for Sustainable Systems by (Staudinger & Keoleian, 2001) which provides an overview of current management of end-of-life vehicles (ELVs) in the United States. The subsequent three studies have been published as a report by Center for Technology, Policy & Industrial Development of Massachusetts Institute of Technology. The first work in this set, discusses the conflicts in meeting recycling objectives facing automakers relating to the other environmental aims such as increasingly stringent fuel economy, emissions, and safety standards. The next study by (Field et al., 1994) provides a systemic representation of the asset flows within the recycling infrastructure and uses it for analyzing potential policies directed toward increasing the recyclability of the automobile. The other study in this set addresses the economic challenges with respect to the material recycling of new design stream in US automotive market (Field et al., 1994). The next study is a master thesis in MIT university (Zamudio-Ramirez, 1994) which proposed a dynamic model for analyzing the interaction among parties in the recycling industry and evaluating the effect of policy changes in this context. The following research proposed a simulation model for material flows and economic exchanges within the US automotive material life cycle chain (Bandivadekar et al., 2004). Kumar & Sutherland (2008) with a survey in past research related to automotive recycling infrastructure; illuminate the limitations of existing works in order to ensure the sustainability of the recovery infrastructure. The last work by (Kumar & Sutherland, 2009) studies the profitability of the business entities in automotive recovery infrastructure in addition to assessing the technological strategy impact. Table 7 shows the highlights of these studies in details.

3.1.4.3. Limitations

Kumar & Sutherland (2008) highlighted the limitations related to works that have been done in the context of recovery infrastructure of ELVs. The first limitation is not considering the complex material flows and their economic impacts within the infrastructure. The authors emphasized that the composition of materials is an important factor in evaluating the profitability of different partners such as dismantlers and shredders. The second limitation is assuming the market factors as the exogenous variables in the developed models wherein some of these variables can be affected by changing the decision parameters. For example, when the US automotive industry is the main consumer of some special materials, any variations in using materials in design of future vehicles has an impact on the used materials price, therefor the price of such materials should be considered as endogens variable in related models. The other limitation is the effect of government policies on different players in recovery infrastructure of ELVs. The authors discussed that the sustainability of this infrastructure in the future can be influenced by the potential policies. And finally they mentioned that developing the variety of scenarios for examining the different impacts of key variables such as market share of new products, recycling technologies or government policies are needed.

Based on the above mentioned limitations, we developed a framework for modeling the business ecosystem of automobile recycling with considering some of the key issues which have not been considered in previous studies. Before explaining the framework in details, definition of the business ecosystem and its application in this research is essential. In the next part, we clarify the concept of the business ecosystem in automobile recycling.

Table 7 : The highlights in literature review

No	Papers/Research Works/Reports	Scope	Highlights
1	The End-of-Life Vehicle (ELV) Directive: The Road to Responsible Disposal :(Konz, 2009)	✓ European Union End-of-Life Vehicle Directive (success and criticism) ✓ United states End-of-Life Vehicle Directive(current situation and future challenges)	➢ In USA no national regulation exists for the disposal of automotive waste ➢ Individual States are free to adopt inconsistent regulations, or forego regulation altogether ➢ Although the EU ELV Directive has a number of inadequacies, it can be considered as an initial model for uniform, federally mandated ELV legislation
2	Management of End-of Life Vehicles (ELVs) in the US:(Staudinger & Keoleian, 2001)	✓ Management of end-of-life vehicles (ELVs) in the United States including (Process, Environmental and Energy Burdens, Economic Assessment, Legislation/Policy, Key Players)	➢ 75% of the overall content of an original ELV reclaimed or Recycled ➢ Disposal of scrap tires, potential mercury releases during ELV processing, and disposal of ASR are three main challenges ➢ It is probable that the US would issue regulations restricting landfill disposal of ASR ➢ US manufacturers are setting internal guidelines based on the European targets for reducing the amount of ELV waste sent to landfill
3	The Recycling of Automobiles: Conflicting Environmental Objectives In A Competitive Marketplace: (Field et al., 1994)	✓ Assessing the economic and technological limitations of automobile recyclability ✓ Comparing the European, US and Japanese approaches for automobile recycling ✓ Automobile industry, its suppliers and consumers, and the government challenges with respect to automobile recycling	➢ Limitation in technological feasibility of selecting materials for increasing recyclability rate ➢ Closed loop recycling is challengeable and costly ➢ Short of reorganizing and vertically integrating ➢ the entire process of recycling ➢ Actual willingness of all stakeholders for burden the associated costs ➢ Landfill use reduction and resource conservation conflict (the appropriate processes for reducing landfills may lead to an inefficient use of a scarce resource)
4	A Systems View of Recycling: (Field et al., 1994)	✓ Assessing the major actors in the recycling of the automobile ✓ Major interactions in the recycling infrastructure ✓ Impacts of Recycling Policy Options including (1) value of the old vehicle, (2) processing costs for existing or new recyclers, (3) value of recycled materials or parts, and (4) the cost of landfill	➢ The value of the old vehicle is derived from the profitability of the rest of the infrastructure ➢ Reducing the processing costs of the existing processors require improvements in the technologies used in segmenting the automobile and segregating the available materials and parts ➢ for establishing new processors, it will be critical that the costs of the existing processes be reduced, or new processes be developed ➢ The maintenance of a strong market for recycled materials and parts will depend upon sustaining the value of these recovered resources ➢ the area of manipulating the cost of landfill can be considered as an area for implementing policy action

5	Recycling of US Automobile Materials: A Conundrum for Advanced Materials: (Field et al., 1994)	✓ 1970's automobile recycling problem, and its resolution ✓ The today automobile recycling problem in US from material point of view	➢ The importance of development in shredders technologies ➢ Pressures upon the automakers to reduce vehicle weight to achieve ever better fuel economy are likely to continue current material trends in the industry(materials with complex recycling process) ➢ Both suppliers and consumers, will be required to face and resolve ➢ The absence of the commitment, the automobile shredder's problems are going to get worse
6	Economics of automobile recycling: (Zamudio-Ramirez, 1996)	✓ An optimization model for assessing dismantling practices ✓ A dynamic model for studying the future situation of automobile recycling in US ✓ Analyzing the role of auto manufacturers	➢ Automobile manufacturers have good opportunities in order to apply certain strategies with participations of other partners in order to sustain the automobile recycling ➢ For applying some of these strategies such as DfD (Design for disassembly) self-maximizing profit goals are not good approaches.
7	A Model for Material Flows and Economic Exchanges Within the U.S. Automotive Life Cycle Chain : (Bandivadekar et al. 2004)	✓ Studying the effect of future changes in vehicle material composition on the automotive recycling infrastructure in US	➢ With significantly higher rates of dismantling and plastics recovery, the amount of ASR per vehicle will remain to increase ➢ The capital costs of the participants within the recycling infrastructure are not important when compared to material acquisition costs. ➢ The disposal costs are not a significant issue affecting the economics of shredding at present ➢ For increasing the economic sustainability of recycling infrastructure the dismantlers may have to attain much higher levels of dismantling than are currently employed
8	Sustainability of the automotive recycling infrastructure :review of current research and identification of future challenges:(Kumar & Sutherland, 2008)	✓ Studying the previous researches in relation to automotive recovery infrastructure ✓ Finding gaps in studies and future challenges	➢ Vehicle changes in design and government policy regulation raise challenges in automotive recovery infrastructure ➢ The models and studies are needed to address the interaction among stakeholders in the infrastructure ➢ Some issues such as energy consumption, using lightweight materials , applying new powertrain technologies should be considered in future studies in automotive recycling infrastructure
9	Development and assessment of strategies to ensure economic sustainability of the U.S. automotive recovery infrastructure:(Kumar & Sutherland, 2009)	✓ Studying the profitability of the business entities in automotive recovery infrastructure ✓ Assessing the technological strategy impact	➢ the economic benefits of achieving higher material recovery rates should be shared by all the stakeholders within the recovery infrastructure ➢ The future of the recovery infrastructure in terms of the amount of ASR is uncertain ➢ combination of technological innovation and government initiative or policy should be assessed for studying the dismantler's profit-enhancement tactics

3.1.5. Business ecosystem of the end of life vehicles players

Peltoniemi & Vuori (2004) believe that business ecosystem is a relatively new concept in the field of business research and by linking this concept to complexity; it is likely to provide new visions to changing business environments. In this part, first we review the value chain and its application in the business context and then explain the business ecosystem concept, its characteristics and justification for using this term for modeling the behaviors of the end of life vehicles players in this study. However, the concept of industrial ecosystem can be used in related to the recovery infrastructure of ELVs based on its features. Because the major objectives in industrial ecosystem analysis are to considering the principles of sustainable development into the industrial actions (Peltoniemi & Vuori, 2004) and efficient using of virgin materials and minimum use of them (Peltoniemi & Vuori, 2004) as well as reducing the waste (Korhonen et al., 2001) but with respect to this fact that automobile recycling in USA is profit driven, the concept of the business ecosystem is more appropriate for demonstrating the behaviors of agents in this environment.

3.1.5.1. Value chain

The concept of the value chain and its applications are not limited to a unique definition or a specific purpose. First time, this concept was described by Porter in 1985 in the context of competitive advantage (Porter, 1996). Based on this description the value chain analysis is mainly used in strategic management and as a tool for strategic planning (Martin, 1995). The applications of the value chain analysis are concerned with recognizing methods in which incomes or profits can be sustained over time (Dahlstrom, & Ekins, 2005).

Focusing on the flow of revenue through the value chain, analysing the business scenarios, allowing the decision making at the extended enterprise and investigation of the strategic capacity issues made the value chain analysis as a practical tools for decision makers (Faße et al.,2009), (Buxton,2006). It facilitates identifying the parties involved in the problem, the interaction and relationship between parties and traces the money and information through the whole value chain as a result of different strategic planning scenarios. However, the concept of the value chain can cover the objectives of evaluating sustainability of ELVs recycling business, but in this problem, as we face with different players as an independent agent, the business ecosystem choice is more suitable. In the next part with defining the business ecosystem, we mention the reasons for this choice.

3.1.5.2. Business Ecosystem

With increasing the business complexity and interrelationship among enteritis, understanding how a decision made by an actor can impact on the other entities becomes a key challenge. And not taking into account of these interactions can lead to unanticipated and possibly undesirable outcomes (Heck & Vervest, (2007), (Peppard & Rylander, 2006), (Erhun & Keskinocak, 2003) cited by (Tian et al., 2008).

Tools which can help modeling the interactions in a network of entities and provide the analysing the impacts of each entity decision on the others in an organized way are crucial for improving business design (Tian et al., 2008). There are several approaches for defining a business ecosystem; in this section we review two of these approaches which are more related to the concept of ELVs recycling.

Based on a definition by (Moore,1998), Business ecosystem is an "extended system of mutually supportive organizations; communities of customers, suppliers, lead producers, and other stakeholders, financing, trade associations, standard bodies, labor unions, governmental and quasigovernmental institutions, and other interested parties. These communities come together in a partially intentional, highly self-organizing, and even somewhat accidental manner." This definition highlights the decentralised decision-making and self-organisation characteristics of business ecosystem (Peltoniemi & Vuori, 2004). Iansiti & Levien (2004) compare the business ecosystem with a biological ecosystem and point out that similar to a network of loosely interconnected participants in a biological ecosystem who depend each other for survival, the situation of each entity in a business network can impact the overall business ecosystem. Peltoniemi & Vuori (2004) according to (Iansiti & Levien 2004) have stated three success factors for a business ecosystem including productivity, robustness and the ability to create niches and opportunities for new entities. These three elements are appropriate for evaluating the infrastructure of ELVs recycling. Because like a business ecosystem this structure needs productivity in order to achieve the expected and desirable outcomes for players, sustainability or robustness to survive in response to environment changes and the ability for building more collaboration in a system of entities who seek values in ELVs recycling chain. Peltoniemi & Vuori (2004) have explained some special characteristics of the business ecosystem. We mentioned these features in Table 8 and for each one brought some justification to show that why the ELVs recycling can be considered as a business ecosystem.

Table 8 : The characteristics of the business ecosystem and ELV evidences

	Characteristics	Definitions	In ELV case
1	Complexity	✓ Many relatively independent parts ✓ Highly interconnected and interactive ✓ Dynamics which arise from the interaction	➢ The independent players in infrastructure ➢ The interaction among dismantlers ➢ The interaction among automakers ➢ The interaction between government and the other players
2	Self-organizing	✓ There is no external or internal leader, who sets goals or controls the system ✓ The events occur spontaneously and due to local interactions ✓ Pattern and regularity emerge without the intervention of a central controller	➢ There is not any central agent in ELVs recovery infrastructure ➢ Players act individually, but affect each other
3	Emergence	✓ The links between individual agent actions and the long-term systemic outcome are unpredictable	➢ The decision made by each players have some certain effects on material markets, car markets or second hand part markets ➢ As the effects can be evaluated by taking into account the interactional effects of players the outcomes of games are unpredictable
4	Co-evolution	✓ The evolutionary mutual changes of species (or organizations) that interact with each other ✓ Strategic changes of one company affect strongly to possibilities of other companies in its ecosystem	➢ Strategic decisions of auto makers can change the profitability of shredders and dismantlers
5	Adaptation	✓ The environment, the adaptive plan, and a measure of performance ✓ Adapts to the external constraints	➢ The government policies can change the design strategy of automakers, or the applied procedures of shredders or dismantlers ➢ The other players design certain strategies based on the regulations and directives of ELVs recovery and act the next action based on the performance measurement (fitness)

3.1.6. The business ecosystem configuration

3.1.6.1. Players and interactions

There are many different players in automobile recycling business ecosystem. However, some of these players are more influential and modeling the behaviors of these actors can illuminate the essential rules in this business network. Figure 24 shows the agents and their interactions in the business ecosystem of automobile recycling. The framework of the model should include the commercial rivals in different markets (material market, car market, used car market, sub-assembly parts market etc.), the behavior of main actors and the potential for monitoring the extracted values from interaction among players as well as considering technological innovations, government policies and social effects. A brief description of key agents and their role in the whole ecosystem has been explained in this part.

3.1.6.1.1. Material suppliers & The market of virgin materials

The automakers efforts in order to reduce vehicle weight and reduce emissions made fundamental changes in future direction of automotive industry (Kumar & Sutherland, 2008). The average new light-duty passenger vehicle sold in the U.S. weighs 1,730 (kg) in 2009. 80% of this weight is incorporated in its powertrain, chassis, and body (Cheah, 2010, p.33). The major materials found in an average automobile in the United States are shown in Figure 22. This figure shows the changes in material composition of Light Vehicle, Model Years1995, 2000, and 2009 according to (Davis et al, 2010). The automotive industry is the main consumer of materials such as lead and rubber and an important user of aluminium, zinc, and ferrous materials (Kumar & Sutherland, 2008). Therefore, it is obvious that the new trend in material consumption, in automotive industry, has impact on material markets and the supply of the main materials suppliers. Cheah (2010) provided the pros and cons of new trend in consumption of High-strength steel, Aluminum, magnesium, Glass-fiber reinforced polymer composite and Carbon-fiber reinforced polymer composite. The increasing costs of manufacturers can translate to increasing the price of cars and this issue can affect the used car and second hand part markets. Recycling of materials such as magnesium can lead to huge increase in the quantity of new scrap in scrap market as a short term effect and Additional magnesium-containing parts (old scrap) as a long term effect (Kamberovic, 2004). Hence the profitability of agents such as dismantlers and shredders can be affected by changing the amount of these materials. Glass-fiber reinforced polymer composite and Carbon-fiber reinforced polymer composite with difficulty in recycling can increase the costs of landfill disposal for shredders and non-ferrous processors.

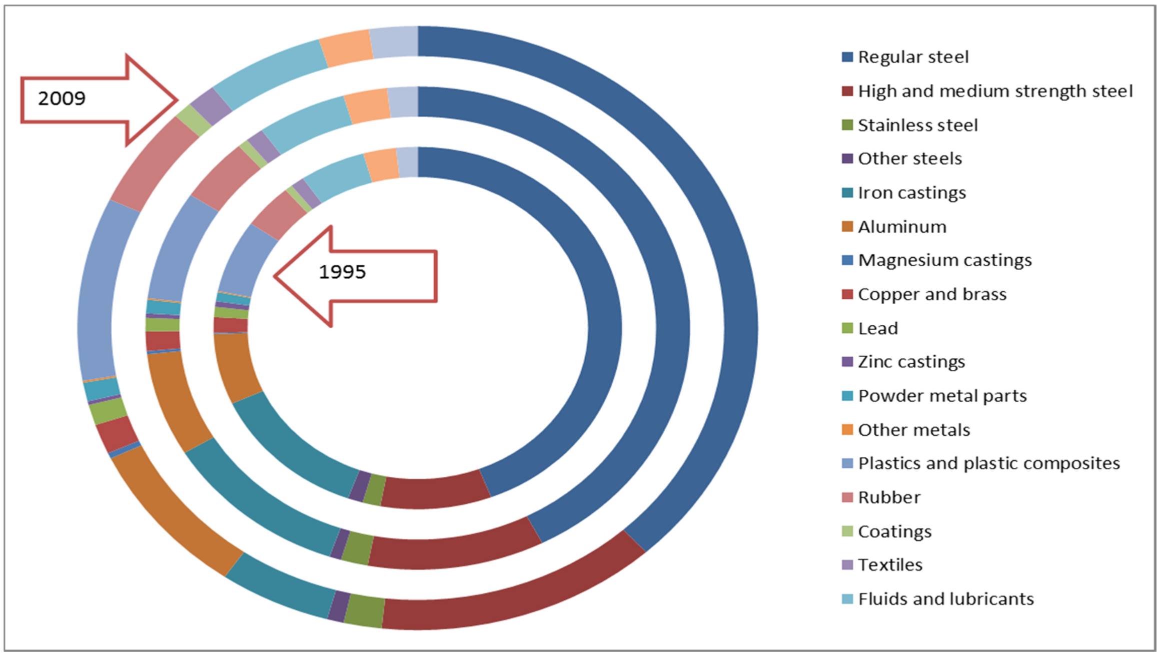


Figure 22 : Material usage in Light Vehicles (1995-2000-2009) according to (Davis et al, 2010)

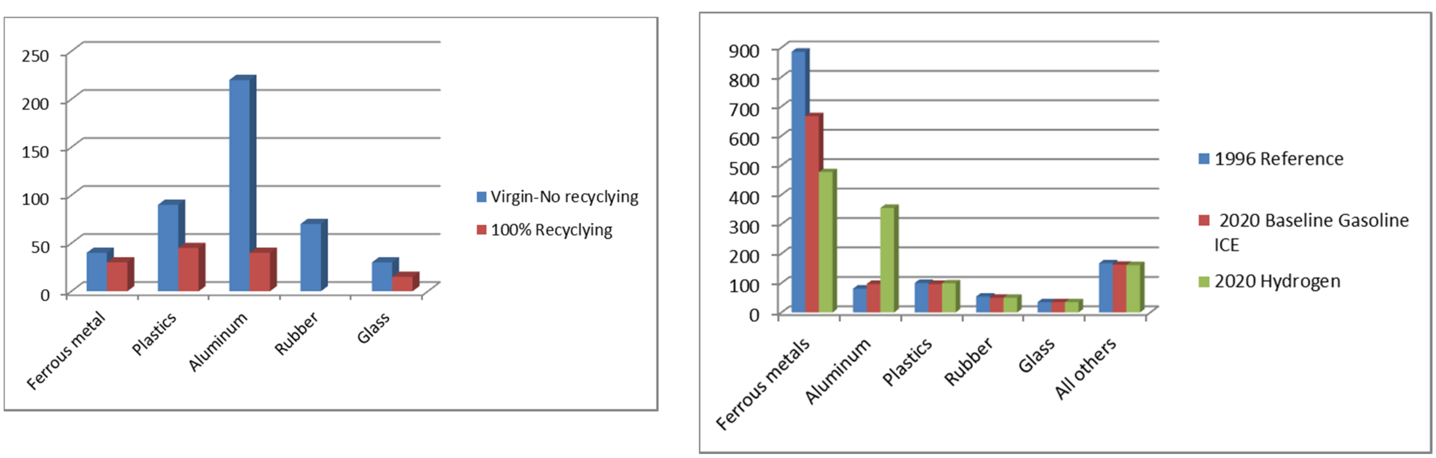


Figure 23 : Energy Required to Produce Vehicle Materials, MJ per kg (a: Left) Selected Materials Usage in Three Vehicle Designs (b: Right) (Reference: Weiss et al., 2000)

3.1.6.1.2. Automakers & The market of vehicles

Gerrard & Kandlikar (2007) present an evaluation framework based on anticipated changes that could result from the ELV Directive. These changes relate to three areas: (a) vehicle design, (b) level of ELV recovery, and (c) information provision. The authors brought the evidences from different automakers in applying different strategies regarding ELVs recycling. Why the different automakers apply the variety of strategies and what are the advantages and disadvantages of different strategies are questions which should be addressed via an appropriate model in order to understand the behaviour of automakers. (Weiss et al., 2000) in their first report of studying the broad impacts of new fuel and vehicle technologies for road transportation, assessed the life cycle of new technologies and the impact on different stakeholders. They considered a family car similar to a Toyota Camry, as a "1996 reference", passenger car vehicle that is likely to evolve by 2020 without radical new technologies or major cost increases, but responsive to calls government or market for improved fuel economy and advanced 2020 technologies all include advanced technologies in the propulsion systems, and make extensive use of lightweight materials and reduction of other driving resistances, aerodynamic drag and rolling resistance. The authors believe that Successful development of new technologies requires acceptance by all major stakeholder groups including private-sector fuel and vehicle suppliers, government bodies at many levels, and ultimate customers for the products and services. Hence, the economic, environmental, and other characteristics of each technology must be assessed for their potential impacts on each of the stakeholder groups (Weiss et al., 2000). According to this study, Energy Required to Produce Vehicle Materials, MJ per kg and Selected Materials Usage in Three Vehicle Designs have been shown in Figure 23 (a,b). In addition, to change in material usage by automakers, and the weight reduction strategies, the design for disassembly is also an important factor. The energy consumed and the environmental impact should also be considered in analysis of the business ecosystem. As discussed above, the different types of vehicles proposed to market based on new technologies and their demand and price should be considered in modeling the business ecosystem.

3.1.6.1.3. Aging agent

The retirement rate of vehicles depends on several factors. These factors are included: Income per capita, vehicle fuel consumption, driving licenced, population, car average age, service price, fuel price, GDP, car import and export rate. Some of important factors have been shown in Figure 24. Zamudio-Ramirez (1994) also considered this agent in his system dynamic model.

3.1.6.1.4. Dismantlers, Shredders & Non-ferrous processors

Based on (Staudinger & Keoleian, 2001) there are two types of dismantlers; High-value parts dismantlers and Salvage/scrap yards. The first type dismantler removes high value parts for resale and sends what remains as hulk to a shredder. The second type dismantler stores ELV and removes the parts gradually. The number of dismantlers in North America is over 12,000. Following the dismantling process, the remaining of ELV is sent to a shredder. The materials separated into two main groups; ferrous metal and non-ferrous materials. At shredder facilities, hulks are inspected prior to shredding to ensure that potentially hazardous components such as batteries, gas tanks, and fluids have been removed. Hulks (and other collected materials) are then shredded into fist-sized pieces using large hammer mills. There are nearly 200 shredder facilities in US. The separated non-ferrous metal fraction (containing aluminum, brass, bronze, copper, lead, magnesium, nickel, stainless steel, and zinc) is typically sent to another, specialized facility to separate the stream into its individual metals by a variety of means. Aluminum and stainless steel are separated by both “light-media” and “heavy-media” plants. In performing these separations, a significant amount of contaminants (non-metals) are removed. This waste, referred to as “heavy ASR,” is sent for landfill disposal (Staudinger & Keoleian, 2001, p.16-19).

The variables that affect the extracted value for dismantler include supply of subassembly parts, the supply of hulk and the environment impact of the process and energy consumed by dismantler during the process of dismantling. However, the existing recycling infrastructure of ELV in US is profit driver (Kumar & Sutherland, 2008) but considering the environmental impact and energy consumed by dismantlers with respect to the future directives are important. In order to evaluate the sustainability of this infrastructure, in addition to assess the economic sustainability, we need to consider the environmental impact and energy consumed by players. For shredders and non-ferrous processors, the supply of scrap, the ASR, as well as environmental impact and energy consumed are considered.

3.1.6.1.5. Landfill

Non-recoverable waste material is sent to landfills for disposal. According to (Staudinger & Keoleian, 2001, p.20), Auto Shredder Residue (ASR) consisting of remaining non-metallic materials – plastics, glass, rubber, foam, carpeting, textiles, etc. is usually sent to landfill. Except in California, ASR is considered a non-hazardous solid waste and thus, can (and is) disposed of in regular municipal or industrial solid waste landfills. The unit cost of landfill (disposal fee) in US depends on the regions and states in US. Every year in the United States about 3 million tons of ASR is landfilled (Jody et al. 1994).

3.1.6.1.6. Government & Society

The effect of government policies on recycling business ecosystem is essential. The government implications can be classified in four categories. The directives related to export and import and tax policy can affect the market of virgin materials as well as car markets. In addition it can influence on retirement rate of vehicles.

The future changes in ELV directives in US including the change in recovery rate, disposal policies and ELVs responsibilities and related charged fees have impacts on automakers, dismantlers, shredders and non-ferrous processors. Partnership for a New Generation of Vehicles (PNGV) for a reduction of 40% in vehicle weight within ten years (Kumar & Sutherland, 2008) and the Corporate Average Fuel Economy (CAFE) in order to improve the average fuel economy of cars and light trucks (trucks, vans and sport utility vehicles) sold in the US :(Kumar & Sutherland, 2008) are the other policies established by US government which can affect automakers strategy in design and subsequently the vehicle and material market. Government as a key player affecting the macro-economic factors such as GDP can also influence the business ecosystem of recycling players.

Society with environment friendly needs, as well as pressures by certain communities, can change the design behavior of automakers, the initiatives and policies of government and subsequently the other agents in the business ecosystem.

3.1.6.1.7. The market of subassembly parts & scrap

According to (Zamudio-Ramirez, 1996) affiliated dismantlers in North America use special information system for suggested price of parts number of parts in stock and other useful information with respect to used parts market in region. The author believes that the interaction of information, supply and demand forms the pricing dynamics of used parts. The change in material usage by automotive industry may change the demand of materials (virgin and scrap) and since the recycling system has a surplus supply in this condition, the price of relevant scrap can be reduced in market. (Zamudio-Ramirez, 1996) has highlighted this issue with an example of steel scrap price in the case of increasing the usage of plastic.

3.1.6.1.8. Technology & Labor market

Technology market is a significant agent in the business ecosystem of recycling. The new technologies in different stages of recycling can improve the sustainability of the recycling infrastructure. In automotive industry, the new technologies can change the trend of material usage, DfD level as well as environmental impact and energy consumed by automakers. For dismantler, the innovation in information system used by dismantler and automation can affect the profit level. Level of innovation in scrap recycling, separation and sorting techniques, and the amount of produced ASR can change the profit of shredders. For non-ferrous processor, the innovation in plastic and tire recycling and the amount of produced ASR can affect the profit level. Moreover, these levels of innovation can change the environmental impact and energy consumed by these players. The marginal cost of dismantler in comparison to market cost of labor is important. Because in some cases removing the parts and selling them in second hand part market considering the labor cost are not profitable and attractive for dismantler. The change in labor market can affect the economic sustainability of dismantlers. On the other side, the change in design for disassembly level can change the operation costs of dismantler and subsequently the demand for labor cost (Zamudio-Ramirez, 1996). Hence, the interaction among labor market, dismantlers and automakers DfD has impact on business ecosystem.

3.1.7. Modeling Robustness of business ecosystem

In this part, we present the introduced framework for modeling robustness of business ecosystem of ELV players. For this framework, we applied the concept of ecosystem robustness. According to (Wilmers, 2007) there are some properties which can be used to understand the resistance or vulnerability of ecosystems. The dynamical effects on persistence, the effects of clusters and networks of species on stability and biodiversity implications of species in response to climate changes and human activities can be considered to evaluate robustness of ecosystems. Hence we used three essential elements for modeling business ecosystem of ELV players including the response to dynamical effects, the stability of ecosystem, performance evaluation and learning effects. These elements will be discussed in details in the next sections.

3.1.7.1. Essentials of the model

As we need to assess the complex dynamic behavior of recycling infrastructure, it is needed to change unit of analysis from firm to group of firms in this business context. The model should reflect interactions among so many players and demonstrate strategic effects of changes in the structure of automobile recycling business ecosystem. Moreover, the model should have the capability to cover wide range of possible future scenarios and their effects on business ecosystem. Kumar & Sutherland (2008) also explained the importance of developing future scenarios include the variables such as market shares of new vehicles, recycling/recovery technologies, and government policies directed at improving recovery rates in studying the dynamics of automobile recycling infrastructure. Morecroft (2007) explained in his book the advantages of scenario planning. He believed that scenario planning provides the ability to make the organization a skill full observer of business environment. The author also emphasized that the models that fit the requirements of executives and scenario planners should have the ability to simulate different thinking about future business options. These models should also be understood by the scenario planners to be communicated effectively to corporate executives and business managers (Morecroft, 2007, p.263). Based on the above descriptions, the essentials of the model have been illustrated in Figure 25. This model has three main parts. The first part aims to address how business ecosystem response to dynamical changes. Hence we need to build a set of appropriate scenarios. Based on market variables, future policies of government, technological changes and the shift in strategies practiced by players, the future scenarios will be designed. The second part of the model is modeling the stability of key players. It means that we need a set of appropriate models for explaining and analysing the behavior of each agent. Modular design of this architecture makes this flexibility for extending the model in next versions. The game theory is an appropriate approach in order to model the stability of ecosystem. And finally based on the reaction of players in different scenarios the extracted value will be monitored. This monitoring approach can reflect the sustainability of business ecosystem in different possible scenarios and the positional shifts of players. In this part, the network outcomes for players and network implications including learning diffusion can be assessed. It should be noted that fuzzy rule base approach can be utilized for performance evaluation of key players.

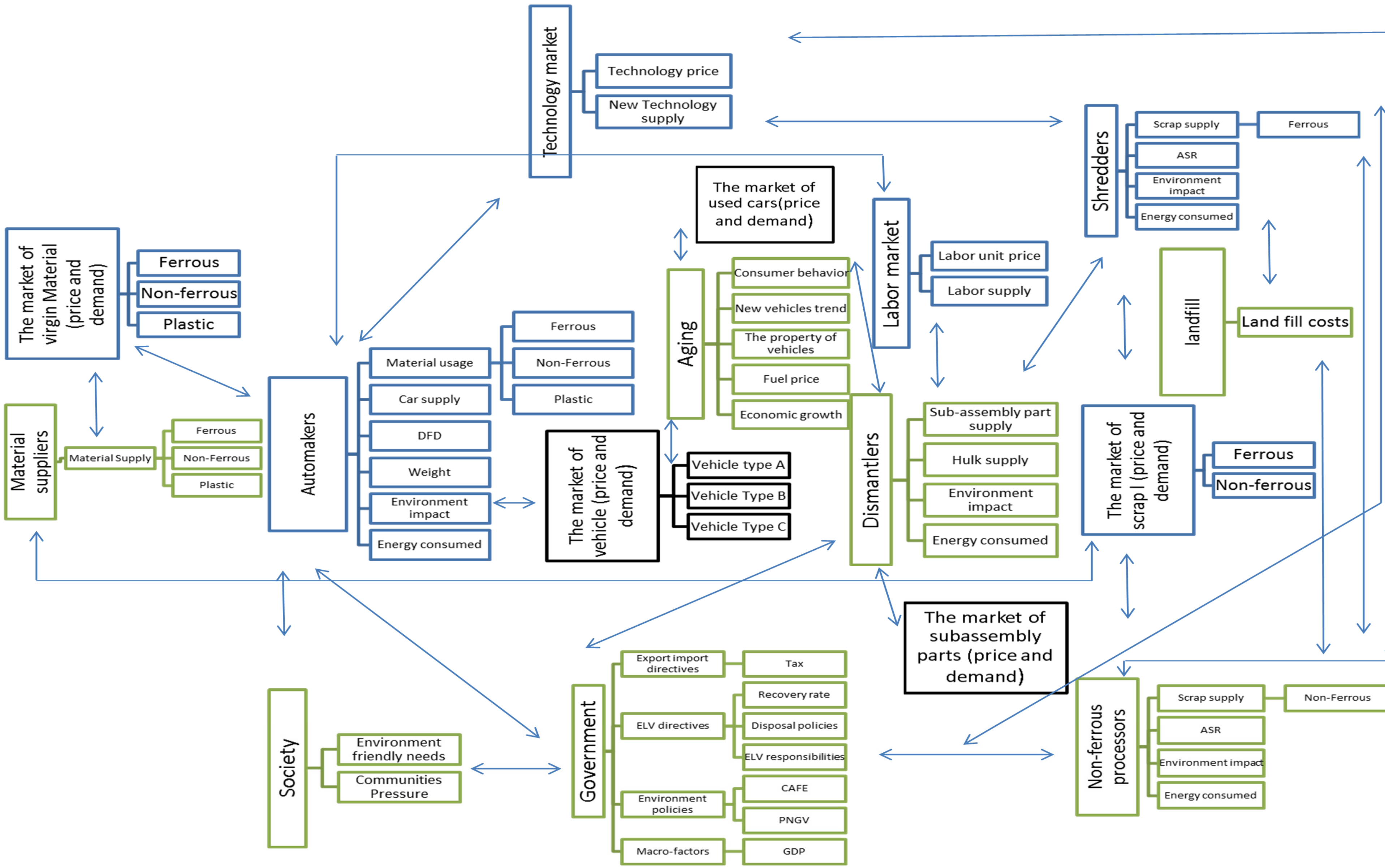


Figure 24 : Key agents in automobile recycling infrastructure and interaction

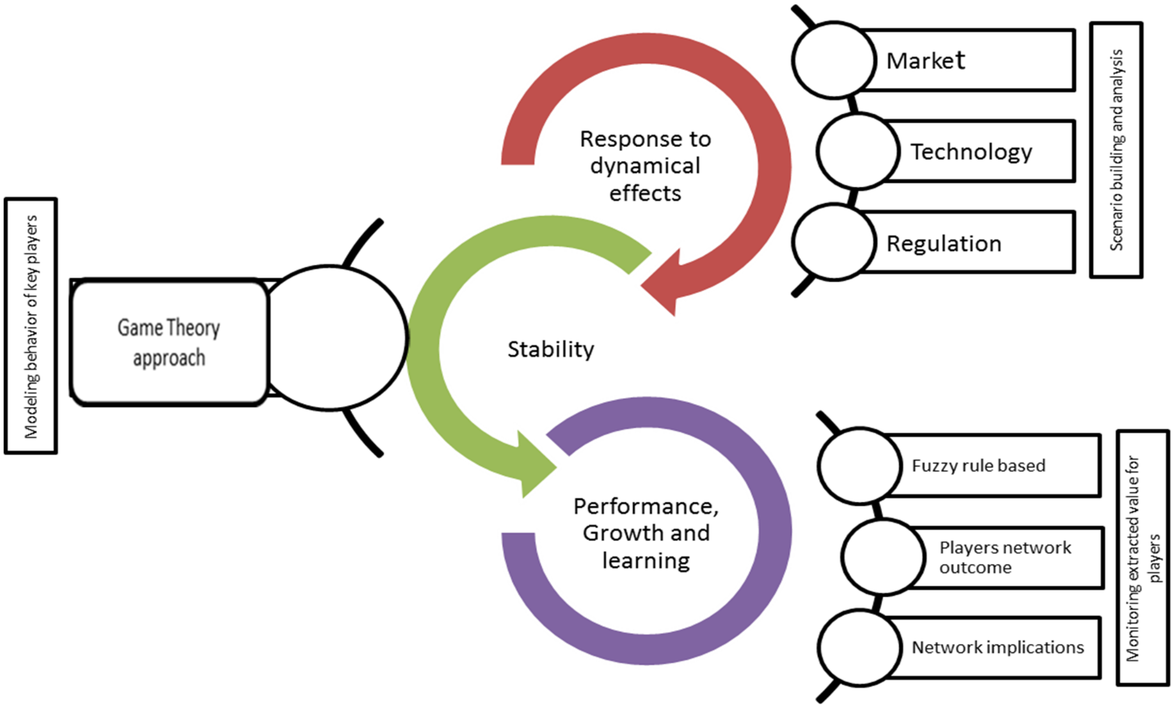


Figure 25 : Essential of the modelling robustness of business ecosystem of ELV players

3.1.7.2. Response to dynamical effects

According to section 3.1.4, technology changes, uncertainty in regulations and market variables are important parameters, which can affect the sustainability of ELV players. In order to assess the effect of these factors, we need a framework to build and analyze the scenarios.

3.1.7.2.1. Scenario building and analysis

First step to build the scenarios is identifying the appropriate attributes. According to conducted literature, the main attributes for building the future scenarios are shown in Table 9. All possible scenarios can be generated from a combination of factors' future trends. For better illustration of different attributes combination for generation the scenarios, an example has been shown in Table 10. In technology part, we considered recycling technology including plastic recycling and separation techniques as well as automobile technology including diesel, hybrid and electric cars. We also considered two types of material composition including aluminum intensive and composite intensive. Regarding the market variables, we considered three trends for market share of different types of automobile technologies. And finally for considering the regulation attributes, we selected recycling rate and banning hazardous substances. For simplifications, we used level 1, 2 or 3 to show different future trends. For example, level 1 for plastic recycling can be explained by small progress in plastic recycling technology. Level 2 can be defined as considerable progress in plastic recycling technology. Hence, scenario 1 demonstrates a scenario with small progress in plastic recycling, small progress in separation technique, an aluminum intensive car with Diesel technology and low market share and recycling rate and banning hazardous substance has been set at level 1.

Two clustering methods including (Fuzzy C-means clustering (FCM) method and SOM (self-organizing map) can be utilized for ranking the scenarios by calculating the degree of possibility, priority and pairwise compatibility for each final scenario. Pishvaee et al. (2008) also used fuzzy clustering-based method for scenario analysis of an Asian pharmaceutical company.

Table 9 : The attributes for building scenarios

Scenario attributes	
Recycling technologies	Plastic recovery
	Separation technologies
Material composition	Ferrous Usage
	Non-Ferrous Usage
	Plastic Usage
	Other-Unrecyclable
New technologies	Hybrid vehicles
	Fuel-cell technologies
	Biofuel
	Composite-Intensive Vehicles
	Aluminium-intensive
	Electric vehicles
Market share	Low
	Medium
	High
Geographic Regions	Regulations
	Transportation costs
	Land fill costs
Policies	Recycling rate
	Banning hazardous materials
	Information and manuals

Table 10 : An example of scenarios generated from attributes

Scenarios	Recyclying Technology				Material composition		Automobile Technology			Market Share			Recyclying Rate			Banning Hazardous Material		
	Plastic Recyclying		Sepeartion		Aluminium Intensive	Composite Intensive	Diesel	Hybrid	Electric	Low	Medium	High	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
	Level 1	Level 2	Level 1	Level 2														
1																		
2																		
3																		
4																		
5																		

3.1.7.3. Stability of ecosystem

In order to assess the stability of ecosystem, we need to study the behavior of players. Considering the interdependency of firms involved in the business ecosystem, the possibility of conflicting interest, the game theory approach would be the appropriate framework for modeling.

3.1.7.3.1. Game theory approach

Cooperative games and non-cooperative games are two approaches, which can be utilized in this context. A cooperative game is a game where groups of players may impose cooperative behaviour; hence the game is a competition between combinations of players, rather than between individual players (Driessen, 1988). This approach can be used in order to evaluate the value splitting among players in different network structure. A non-cooperative game is a game in which players make decisions individually. This approach can be used in order to focus on behavior of some players (for example, manufacturers and regulation bodies, or manufacturers and competitors) however, in order to present the network value, this approach has some limitations. In conventional game theory, there are three assumptions: (1) rational behavior of all the agents, (2) complete sharing of empirical information, (3) all the agents have common knowledge of these assumptions (Barari et al., 2012). As in the real world, considering these assumptions is difficult or even impossible, applying evolutionary game theory can bring the most advantages for modeling the behaviors of players. In Evolutionary game theory instead of directly calculating properties of a game, populations of players using different strategies are simulated and, a process similar to natural selection is used to determine how the population evolves. Varying degrees of complexity are required to represent populations in multi-agent games with differing strategy spaces. Zhu & Dou (2007) used evolutionary game theory in order to investigate the games between governments and core enterprises in greening supply chains. (Barari et al., 2012) applied evolutionary game for analyzing the game between the producer and the retailer to adjudicate their strategies to trigger green practices with the focus on maximizing economic profits. Geçkil & Anderson (2009) also used game theory approach for analysing the game among government and automakers in for regulations regarding CAFE (corporate average fuel economy) standards in US. Table 11 illustrates different approaches in game theory, and potential application in the context of business ecosystem of ELV players.

Table 11 : The game theory approaches in green context and potential application in the context of business ecosystem of ELV players

Game theory approaches		*Studies in green context*	*Application in modeling business ecosystem of ELV players*
Non cooperative game (one stage or extensive form)	Nash equilibrium	CAFÉ Standards and Competing Automakers (Geçkil & Anderson, 2009)	The game between automakers and government regarding ELV regulations
	Evolutionary equilibrium	Green supply chain contracts(Zhang, & Liu, 2012) Governments and Core Enterprises in Greening Supply Chains (Zhu & Dou, 2007) Coordination mechanism in three-level green supply chain under non-cooperative game (Barari et al., 2012)	The game between automakers in order to apply design for the end of life practices The game between dismantlers/shredders/non-ferrous processors for setting the price
Cooperative game (one stage or extensive form)	Coalition game		Coalition game among automakers, research centers and recycling bodies
Economic game (one stage or extensive form)	Oligopolistic game (Cournot, stackelberg and Bertrand game)	Price Competition and Product Differentiation When Consumers Care for the Environment Conrad, 2005) Environmental quality competition and eco-labeling (Amacher et al., 2004) The greening of the market (Kuhn,200)	The game between automakers in order to apply design for the end of life practices The game between dismantlers/shredders/non-ferrous processors for setting the price

3.1.7.4. Performance Evaluation, Learning and Growth

Considering the availability of data, the uncertainty of the problem and existence of data based on common sense, experience and intuitions, fuzzy rule based approach also can be a useful tool for modeling. Moreover, learning, evolution and growth are the other properties of a business ecosystem which play key role in its robustness.

3.1.7.4.1. Fuzzy rule based approach

Yuan (2009) explains the advantages of fuzzy logic in comparison to simulation, stochastic and probabilistic methods. With considering the complexity or costly of applying mathematical and stochastic models for small or medium size firms, probabilistic models requirement and the problem of accommodating dynamic business conditions with the assumption of these models, the author addresses the need for a practical and simplified method which minimize these complexities. In the context of economic, environmental and social analysis of key players in automobile infrastructure, we have the same problems in applying the probabilistic and stochastic models. The size of players, the uncertainties in input variables and the lack of data availability are the reasons for utilizing fuzzy based approach in analyzing the key player's sustainability.
Certain sub models for calculation of sustainability of players can be developed. Each model has three parts for evaluation of economic, environmental and social sustainability of key players such as dismantlers, shredders, nonferrous processors and auto manufacturers. Figure 26 illustrates a preliminary application of Fuzzy rule based in order to assess the sustainability of dismantlers. For economic performance, we used three layers Mamdani's model. First layer is included fixed cost, volume, variable cost and revenue. For operation cost, we considered separation technology, information technology, type of car, labor skills and labor price. For transportation cost, we considered distance and unit price of hulk transportation. For revenue, we considered the revenue of parts and hulks. The environmental performance can be evaluated considering technology, type of car, labor skill and the distance for hulk transportation. For social performance, we considered employment rate, the health and risk for labor and health and risk for local residences. And finally the sustainability index can be obtained. This framework only used as an example, the detailed application, parameters, rules and numerical examples are performed by authors and will be published as further studies .

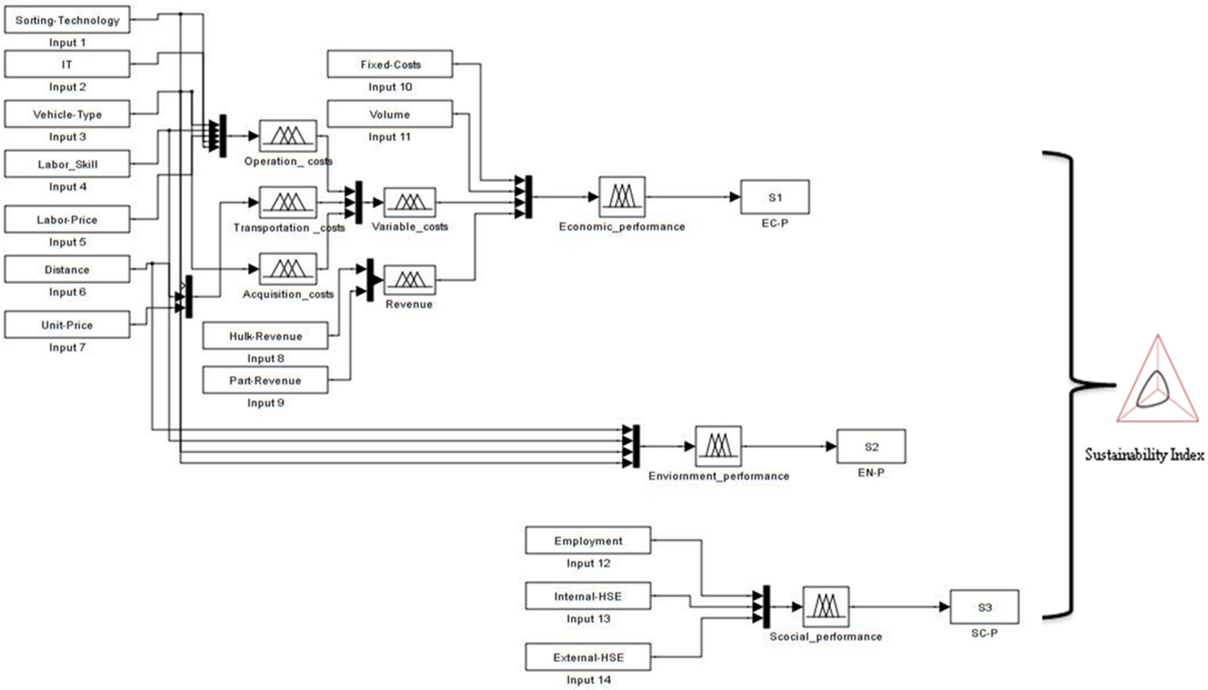


Figure 26 : Application of Fuzzy rule based model for evaluation of sustainability of dismantlers

3.1.7.4.2. Players network outcomes & Network implication

Social network analysis literature is full of different measures and functions which can be used in order to study business ecosystem of players. However, some of these measures can provide highlights with respect to functionality and efficiency of network. According to (Jackson, 2008), there are two challenges in modeling networks from a strategic point of view. Explicitly model the costs and benefits that arise from various networks and how the individual incentives translate into network outcomes. In addition since the sharing information and opinions formation are important characteristics of social networks, how the structure of the network can affects learning and information diffusion are needed to be considered in social network analysis. The dynamic characteristic of network of ELV players needs to be considered in order to evaluate the synergy in stakeholder's network. The utility of player or pay-off player represents the net benefit that a player receives in a particular network. The costs and benefits of interaction and different types of allocation rule (player based or linked based) are discussed in this part (Jackson, 2008). Influence and learning effect are the other issues in the modeling business ecosystem. The first one determines which players have the most influence over the opinions (Jackson, 2008) and the learning determines how quickly players learn and how the information can be aggregated in the network (Jackson, 2008). As the communities and media are important stakeholders, these measures can determine most influential players and the structure which lead to a convergence of opinions more quickly.

3.1.8. Summary

An essential part of modeling and analysis of ELV recycling infrastructure is to capture the dynamic interactions among entities in this network of players. Considering the concept of business ecosystem, we proposed a framework to integrate modeling and analysis of the complex interaction among players in automobile recycling infrastructure. More work is required to develop an integrated model in order to consider a variety of factors which have been explained in this study. This study provided a research agenda for the modeling business ecosystem of ELV players.

References

Amacher, G. S., Koskela, E., & Ollikainen, M. (2004). Environmental quality competition and eco-labeling. Journal of Environmental Economics and Management, 47(2), 284-306.

Bandivadekar, A. P., Kumar,V., Gunter, K. L., and Sutherland, J. W. (2004) A Model for Material Flows and Economic Exchanges Within the U.S. Automotive Life Cycle Chain, Journal of manufacturing system, Vol.23/No.1,pp. 22-29

Barari,S. et al.,2012," A decision framework for the analysis of green supply chain contracts: An evolutionary game approach" Expert Systems with Applications 39 ,2965–2976

Buxton,D., Farr, R and Maccarthy, B. "The Aero-Engine Value Chain Under Future Business Environments: Using Agent-Based Simulation To Understand Dynamic Behaviour , MITIP2006, 11-12 September, Budapest

Cheah, L. W. (2010) Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S. , PhD thesis, Massachusetts Institute of Technology

Conrad, K. (2005). Price competition and product differentiation when consumers care for the environment. Environmental and Resource Economics, 31(1), 1-19.

Dahlstrom and Ekins, (2005) Combining economic and environmental dimensions: Value chain analysis of UK iron and steel flows, Ecological Economics 2005

Davis, S., S. Diegel, and R. Boundy, (2010) Transportation Energy Data Book. 30 ed., Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Erhun, F. and Keskinocak, P. (2003), Game Theory in Business Applications, Working Paper, Stanford University, www.stanford.edu/;ferhun/paper/GT.pdf.

Faße, A., Grote, U., & Winter, E. (2009). Value chain analysis methodologies in the context of environment and trade research (No. 429). Discussion papers//School of Economics and Management of the Hanover Leibniz University.

Field, F. R., Ehrenfeld, J. R., Roos, D., & Clark, J. P. (1994). Automobile recycling policy: background materials. In Report prepared to support and accompany a paper presented to the Automotive Board of Governors, World Economic Forum, Davos, Switzerland.

Geçkil, I. K., & Anderson, P. L. (2010). “Applied game theory and strategic behavior”. Chapman & Hall.

Gerrard , J., Kandlikar.M.(2007), Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on ‘green’ innovation and vehicle recovery, Journal of Cleaner Production 15 -17e27

Gomes.C. (2012), Global Auto Report, Global Economic Research, available at: http://www.gbm.scotiabank.com/English/bns_econ/bns_auto.pdf

Heck, E. V. and Vervest, P. (2007) Smart Business Networks: How the Network Wins,’’ Communications of the ACM, 50, No. 6, 28–37

Heyman, E.,2012,”US car market: Returning to its previous size www.dbresearch.com

Kamberovic, Z. J. (2004). Possibilities of recycling of magnesium and magnesium alloys. Association of Metallurgical Engineers Serbia and Montenegro, 10(3), 261-267.

Jackson, M., (2008),”Social and Economic Networks “,Princeton University Press

Kanari,N., Pineau, J.-L. and Shallari, S. (2003) End-of-Life Vehicle Recycling in the European Union, Journal of the Material, pp. 15-19

Konz, R. J., (2009) The End-of-Life Vehicle (ELV) Directive: The Road to Responsible Disposal, 18 Minn. J. Int'l L. 431

Kuhn, M. (2005). "The greening of markets: product competition, pollution and policy making in a duopoly". Edward Elgar Publishing.

Kumar, V. and Sutherland, J.W. (2008) 'Sustainability of the automotive recycling infrastructure: review of current research and identification of future challenges', Int. J. Sustainable Manufacturing, Vol. 1, Nos. 1/2, pp.145–167.

Kumar,V. and Sutherland, J.W. (2009) Development and assessment of strategies to ensure economic sustainability of the U.S. automotive recovery infrastructure, Resources, Conservation and Recycling 53 470–477

Martin, J. (1995), The Great Transition: Using the Seven Disciplines of Enterprise Engineering. New York

Morecroft, J. (2007), Strategic Modelling and Business Dynamics: A Feedback Systems Approach, Wiley

Peltoniemi, M. and Vuori, E. (2004) 'Business ecosystem as the new approach to complex adaptive business environments', Proceedings of eBusiness Research Forum, Tampere.

Peppard,J.and Rylander, A. (2006), From Value Chain to Value Network: Insights for Mobile Operators,'' European Management Journal 24, No. 2, 128–141

Pishvaee, M. S., Fathi, M., & Jolai, F. (2008). A fuzzy clustering-based method for scenario analysis in strategic planning: the case of an Asian pharma ceutical company. S. Afr. J. Bus Manage, 39(3), 21-31.

Porter, M. E. (1996), What is strategy? Harvard Business Review, November–December, 61-78.The value chain 1996

Staudinger,J.& Keoleian,G.,2001," Management of End-of Life Vehicles (ELVs) in the US" ,a report of the Center for Sustainable Systems,Report No. CSS01-01

Tian, C. H. et al., 2008 “BEAM: A framework for business ecosystem analysis and modeling,,IBM System Journal, VOL 47, NO 1

Weiss, M. A., Heywood, J.B., Drake, E. M., Schafer, A. and AuYeung, F. F., (2000), ON THE ROAD IN 2020: A life-cycle analysis of new automobile technologies, Energy Laboratory Report # MIT EL 00-003, http://web.mit.edu/energylab

Wilmers, C. C. (2007). Understanding ecosystem robustness. Trends in Ecology & Evolution, 22(10), 504-506.

Yuan, F., 2009, The use of a fuzzy logic-based system in cost-volume-profit analysis under uncertainty,Expert Systems with Applications,, Volume 36, Issue 2, Part 1, March 2009, Pages 1155–1163

Zamudio-Ramirez,P. (1996) Economics of automobile recycling, Master thesis, MIT

Zhang, C. T., & Liu, L. P. (2012). Research on coordination mechanism in three-level green supply chain under non-cooperative game. Applied Mathematical Modelling.

3.2. Economic Sustainability of End-of- Life vehicle recycling infrastructure under uncertainty (A fuzzy logic approach)

3.2.1. Résumé

Cet article présent une approche de modélisation basée sur la logique floue pour analyser la viabilité économique des véhicules en fin de vie, dans un cadre incertain. L'approche de modélisation proposée considère différents types de sources d'incertitude causés par la modification apportée aux conceptions par les fabricants d'automobiles, le marché de la technologie et de la réglementation qui fournissent un cadre de travail aux fabricants d’automobiles pour évaluer l'impact des stratégies de conception sur les infrastructures de recyclage automobile pour assurer des pratiques de conception Eco-durable. De plus, l'approche proposée peut être utilisée par les gestionnaires de recyclage afin d'analyser leur marge de profit dans différents scénarios et de faciliter le processus de prise de décision.

Mots-clés: Démolisseurs, véhicules en fin de vie, logique floue

3.2.2. Abstract

This paper presents a modeling approach based on fuzzy logic based system in order to analyze the economic sustainability of End of life vehicle (ELV) dismantlers under uncertainties. The proposed modeling approach with considering the different types of uncertainty including auto manufacturers design changes, technology market and regulations provides a framework for auto manufacturers to evaluate the impact of design strategies on automobile recycling infrastructure for ensuring sustainable Eco design practices. Moreover, the proposed approach can be utilized by managers of recycling business entities in order to analyze their profit margin in different scenarios and facilitate the decision making process.

Key words: ELV dismantlers, Economic sustainability, Fuzzy logic based system, Uncertainty

3.2.3. Introduction

Vehicles affect the environment over their entire life cycle. Some of these effects occur at the end of their lives such as the hazardous substance emissions, and disposals [1]. Addressing the environmental issues for ELVs raises a number of serious challenges for the automotive industry. In some countries such as USA, there is no specific legislation regarding the management of ELVs. With respect to the broad landfill spaces with lower costs of waste disposal and lack of standard waste legislation for whole states, recycling industry has received much less interest [2]. In the absence of the identical legislation in auto recycling, automotive OEMs follow different strategies in a variety range, from changes in design to issue a guideline or standards. Each of these strategies has also different impacts on the key players such as dismantlers, shredders and non-ferrous processors and even can change the economic sustainability of ELVs business [3].

In the USA, the infrastructure related to the recovery and recycling of ELVs is more or less profit driven. The players in this business such as dismantlers or shredders should be gainful to stay in this business [3]. All these reasons make the infrastructure of recycling ELVs in USA, an attractive area for assessing the business and economic issues, the games between players and the challenges facing the key decision makers.

Car dismantlers are one of the essential players in automobile recycling infrastructure, which their economic sustainability is crucial. These entities face a lot of uncertainties in their business. The sources of these uncertainties come from market parameters, auto manufacturers design, regulation, technology market and competitors activities. In this paper, with providing a review on related studies, we developed a framework based on fuzzy based modeling approach in order to analysis the dismantler's profitability under uncertainty. In section two, we provide a brief literature review in ELV processing; recycling infrastructure and the modeling approaches for analysis the profit of dismantlers. In section three, we explain the fuzzy based modeling approach and its advantages. Section four explains the developed framework and their parameters. In section five, we propose the future studies and conclusion.

3.2.4. Literature review

In this part, we review the ELV recycling process, the key players and the economic models, which are developed in order to analyze the profit of dismantlers.

3.2.4.1. ELV recycling

We used ELV as a generic term in order to build integrity with the other references used in this study. In this study, we focused on passenger vehicle. The general process of recycling a passenger car was illustrated in Figure 27.

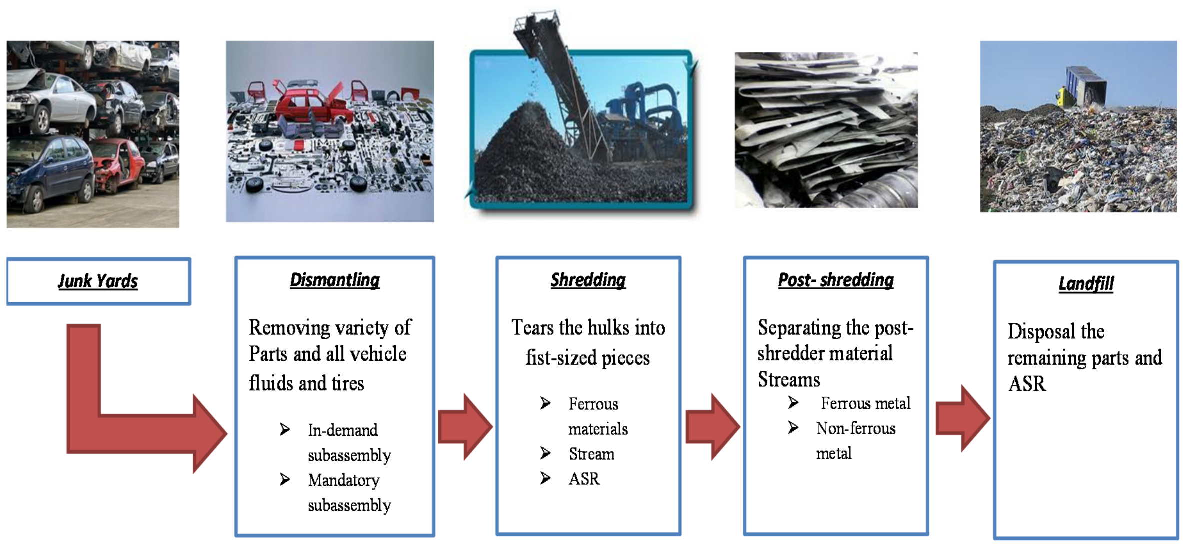


Figure 27 : General process of recycling a passenger car

There are many different players in automobile recycling infrastructure. However, some of these players are more influential and modeling the behaviours of these actors can illuminate the essential rules in this business network. Dismantlers, shredders and non-ferrous processor are the main actors in automobile recycling infrastructure. In this study, we focused on dismantlers activities.

3.2.4.2. Dismantlers

According to [4], there are two types of dismantlers; High-value parts dismantlers and Salvage/scrap yards. The first type dismantler removes high value parts for resale and sends what remains as hulk to a shredder. The second type dismantler stocks ELV and removes the parts gradually. The number of dismantlers in North America is over 12,000 [4]. Following the dismantling process, the remaining of ELV is sent to a shredder. The variables that affect the extracted value for dismantler include supply of subassembly parts, the supply of hulk and the environment impact of the process and energy consumed by dismantler during the process of dismantling. The existing recycling infrastructure of ELV in US is profit driver [3] but considering the environmental impact and energy consumed by dismantlers with respect to the future directives are also important.

3.2.4.3. Economic sustainability of Dismantlers

In this study, we focused on some key works which studied the key aspects of dismantler's economic model or introduced a model in order to analyze the profitability of dismantlers in recycling infrastructure. The first study is a report of the Center for Sustainable Systems [4], which provides an overview of current management of end-of-life vehicles (ELVs) in the United States. The authors believe that no matter which type of operation employed by dismantlers, basic income to dismantlers outcomes from sales of removed parts and materials, along with sale of the remaining hulk to the shredder. They introduced total fixed and variable costs, ELV acquisition costs, dismantler income; from recovery of catalytic converters, batteries, tires, fluids, hulk sales income and the cost of transport hulks to the shredder, as the parameters involved in dismantler's profit.

The next study is a master thesis in MIT University [5] which proposed a dynamic model for analyzing the interaction among parties in the recycling industry and evaluating the effect of policy changes in this context. The objective of the model is to calculate the amount of material recycled by dismantlers. Three variables have been considered in this study; Fraction of non-ferrous material, the fraction of plastic and the fraction of mass. In this model, it has been assumed that approximately 50% of all parts can be sold.

Work done in [6] introduced a technical cost model for the ELV processing infrastructure to analyze the economics of the activity of dismantling and shredding infrastructures. This involved detailed vehicle breakdown and the characterization of dismantlers and shredders activities in terms of material and economic flows. As a result, this model provided dismantler costs and revenues as a function of dismantling rates which defined as the mass of parts dismantled (based on the reference ELV weight). They assumed typical car parts with given material compositions and a linear relation to evaluate dismantling times and costs.

Works done in [7], [8] proposed a simulation model for material flows and economic exchanges within the US automotive material life cycle chain. In this model, the dismantler's monthly profit is calculated as the difference between revenue (from part, material, and hulk sales) and costs (purchase of ELVs, labor, transportation, and disposal). The revenue parameters include number of parts sold and part values, the amount of material scrap and scrap prices, and the number of hulks sold. The costs parameters are: labor rate, time required for dismantling (which is again dependent on the fraction of materials the dismantler intends to recover), number of ELVs purchased, purchase price paid for the ELVs, amount of material disposed after removal and cost of disposal.

Work done in [3] with a survey in past research related to automotive recycling infrastructure; illuminates the limitations of existing works in order to ensure the sustainability of the recovery infrastructure. The authors note that vehicle changes in design and government policy regulation raised challenges in the automotive recovery infrastructure. They believe that new models and studies are needed to address the interaction among stakeholders in this infrastructure. Some issues, such as energy consumption, using lightweight materials and applying new powertrain technologies should be considered in future studies of the automotive recycling infrastructure.

Variable uncertainties, the size of dismantlers and the complexity of applying the statistical and mathematical analysis in order to have an estimation of profit, based on the different types of car in the market and other internal and external factors are the challenges, which should be considered in modeling. Moreover, technology effect (the information system, tools and techniques used by dismantlers), the influence of labour skills on variable costs, the effect of design for disassembly (DFD), warranty, age and composition of materials on acquisition costs are also essential parameters. Hence, we developed a framework for analyzing the profit of dismantlers to consider these elements.

3.2.5. Fuzzy logic based system approach

Before explaining the fuzzy based system, it is necessary to explain the fuzzy logic concept. Fuzzy logic is the theory of fuzzy sets. These sets unlike Boolean logic, which has two values are multi-valued and show the degrees of membership and degrees of truth. Hence they can express the vagueness of a variable. In other word, an element belongs to a fuzzy set with a certain degree of membership [9].

The study in [10] explains the advantages of fuzzy logic in comparison to simulation, stochastic and probabilistic methods. With considering the complexity or costly of applying mathematical and stochastic models for small or medium size firms, probabilistic models requirement and the problem of accommodating dynamic business conditions with the assumption of these models, the availability of probabilistic data on relevant inputs for simulation techniques, the author addresses the need for a practical and simplified method which minimize these complexities. Work done in [10] states that "Historical distributions do not always cast light on unfolding future events [11]; as such, they are inadequate for handling conditions involving uncertainty. Fuzzy logic is used for reasoning about inherently vague concepts [12], such as 'profit is good or not', where level of profit is open to interpretation. A firm's projection of profit is based on relatively precise forecasts of sales and cost behavior."

In the context of economic analysis of key players in automobile infrastructure, we have the same problems in applying the probabilistic and stochastic models. The size of dismantlers, the uncertainties in input variables, the lack of data availability are the reasons for utilizing fuzzy based approach in analyzing the dismantler's profitability.

3.2.5.1. Modelling Framework

In conventional model for analyzing the profit, four important variables are considered. These variables are fixed costs, variable costs, sales volume in units and the selling price. In order to develop a model for profit analysis of a dismantler, we considered four types of costs including the acquisition costs of a car, fixed cost, operation cost and transportation cost. The acquisition cost depend on some inputs such as age of car, the warranty, the design for disassembly level, the commonality of parts for using in the other models, the weight (nonferrous usage and non-metal mass usage in the car). The fixed cost is determined based on the size of dismantler and the tools used by it. The operation costs depend on the labour cost, time for processing a car and the complexity inherent in this process. The transportation cost is determined based on weight, distance and unit price of transportation. We also considered two other input for profit; revenue and a factor based on the innovation level of tools and information system used by dismantler. The revenue is extracted from selling the removed parts, batteries, fluid and tiers and the revenue from selling hulk to shredder. The model is illustrated in Figure 28. The inputs of the models, which are crisp values, need to be converted to a linguistic level. The linguistic variables can enter to the fuzzy model with no change. All inputs are entered to a fuzzy rule based Mamdani's model and after combining all outputs, the defuzzification process will be performed to extract a numeric value for the profit.

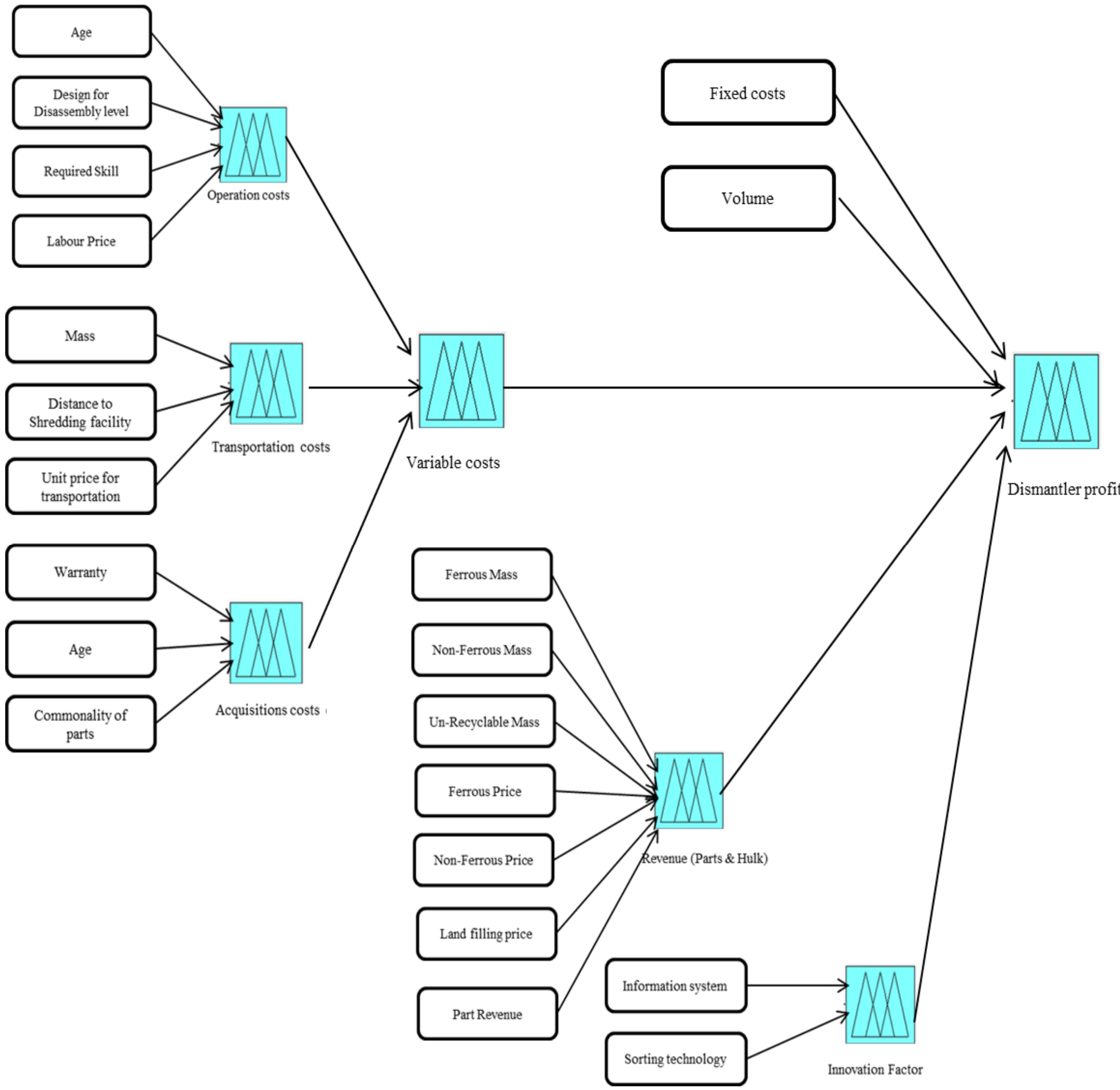


Figure 28 : Fuzzy rule based approach for dismantler's profitability analysis

3.2.6. Decision support tool

3.2.6.1. Decision tool overview

A decision support tool is developed for modeling this approach. We used Matlab Simulink, Fuzzy and Guide Toolbox for developing this decision tool. The model has been designed based on different types of car which are dismantled. The total profit of dismantler is calculated based on the sum of profit of different types and their volumes (See Figure 29).

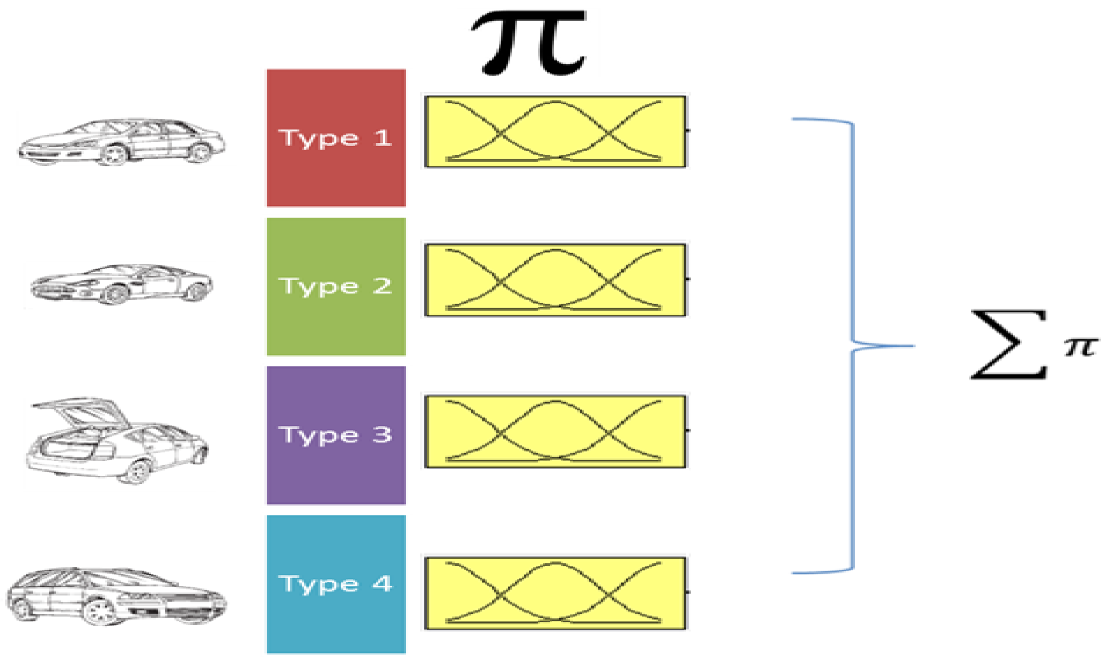


Figure 29 : Dismantler's total profit

The overall procedure has been shown in Figure 30. First of all, it is needed to develop fuzzy Mamdani's models for seven sub models including (operation costs, transportation costs, acquisition costs, variable costs, revenue, innovation factor and profit). The next step is utilizing Matlab Simulink to link the different sub models and finally using interface in order to perform experimental design and sensitivity analysis.

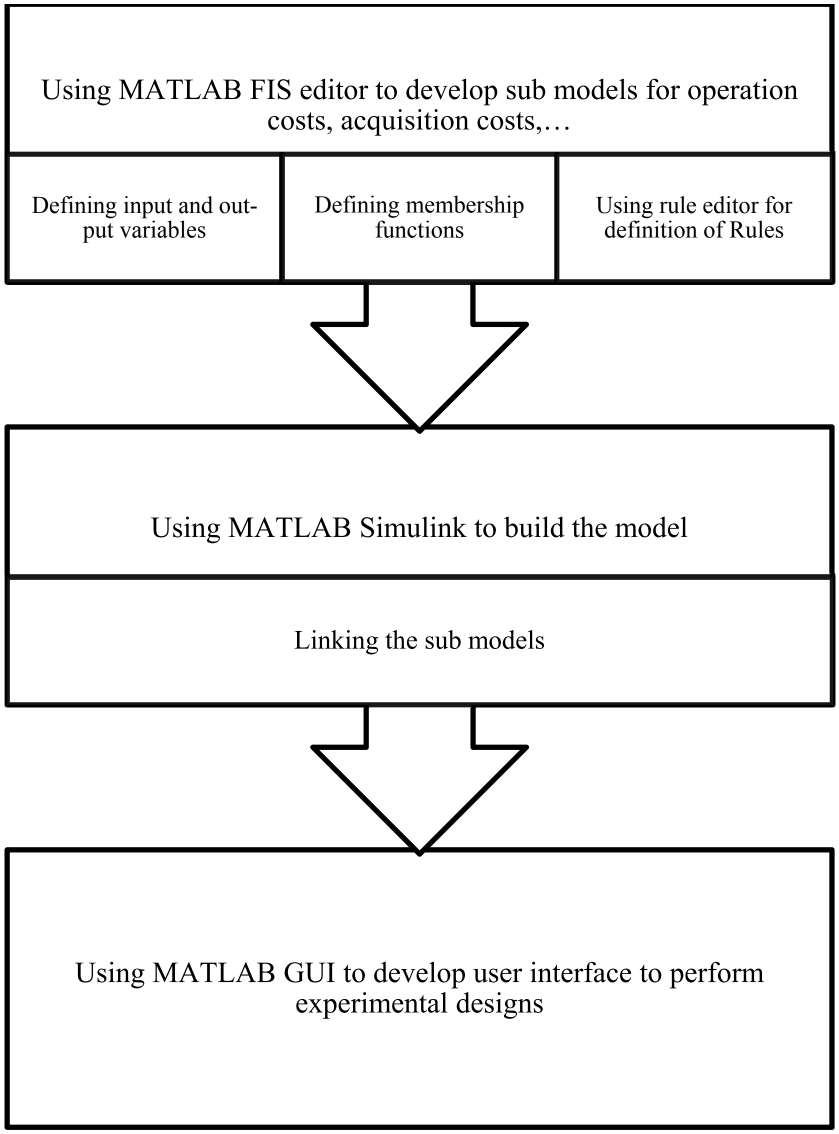


Figure 30: Decision tool in one look

3.2.6.2. Developing sub models

For each sub model, we need to define input and output variables. We utilized FIS editor of Matlab to define the variables, membership functions and the relevant rules. Figure 31 illustrates FIS editor for Acquisition costs. We have three input variables including Age, Warranty and commonality of parts. The output variable is acquisition cost. After this step, we need to define the membership functions for each variable as well as the range of them. In this study, we used triangular fuzzy number. The rules have been defined in rule window based on the information have extracted from literature review. See the Figure 32 for rule window of Acquisition costs.

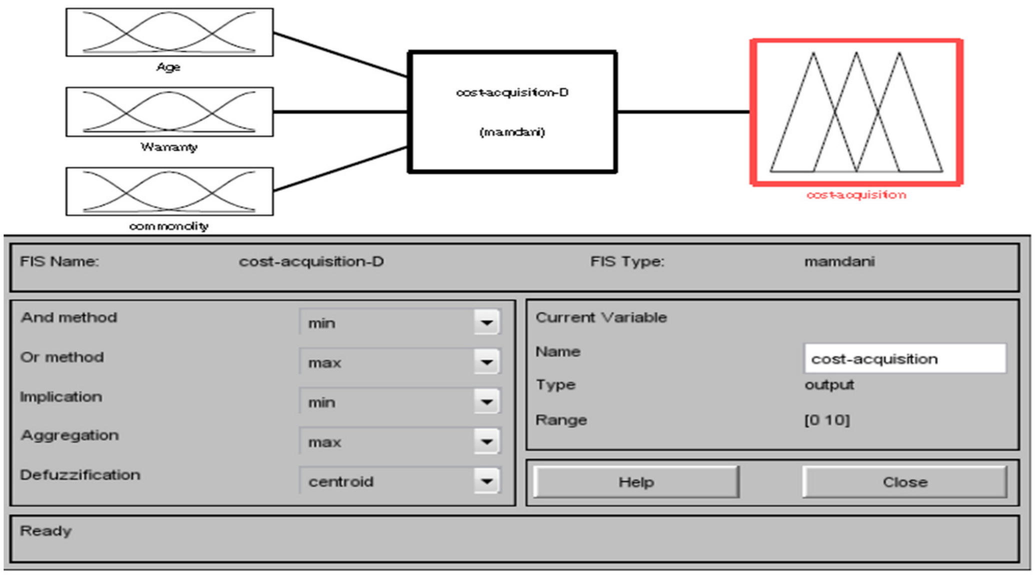


Figure 31 : Sub model for Acquisition costs

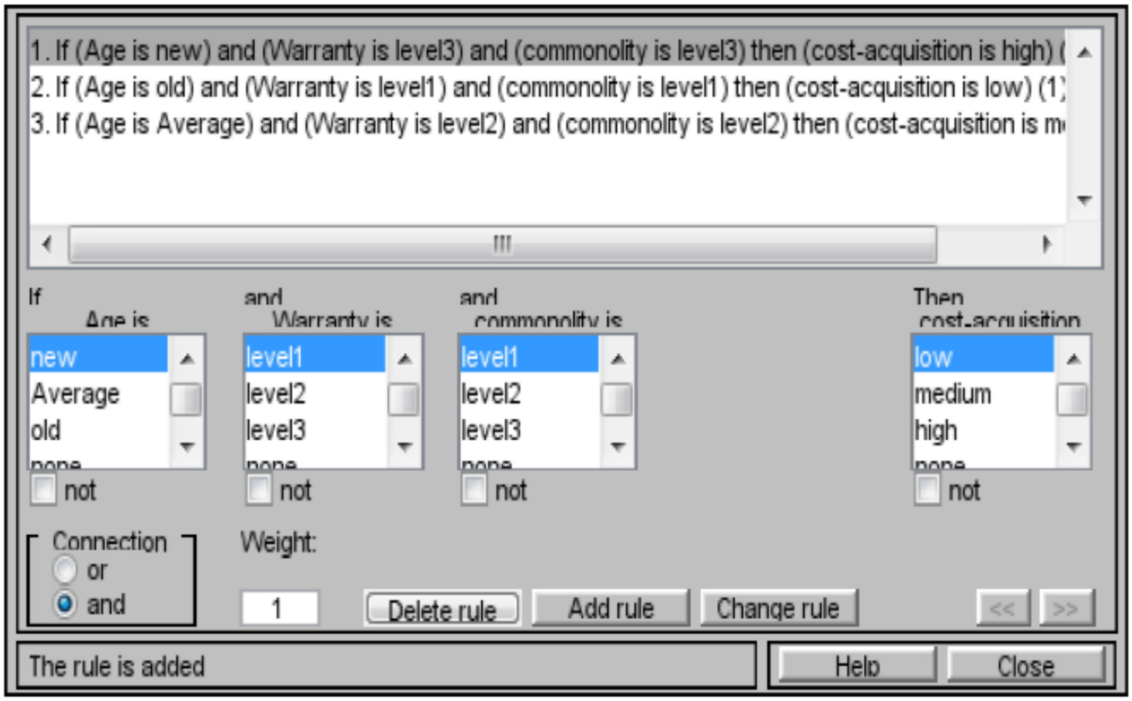


Figure 32 : Rule window for Acquisition costs

After definition of rules for each sub model, we can see the rule surface and relationship between the inputs and output as shown in Figure 33.

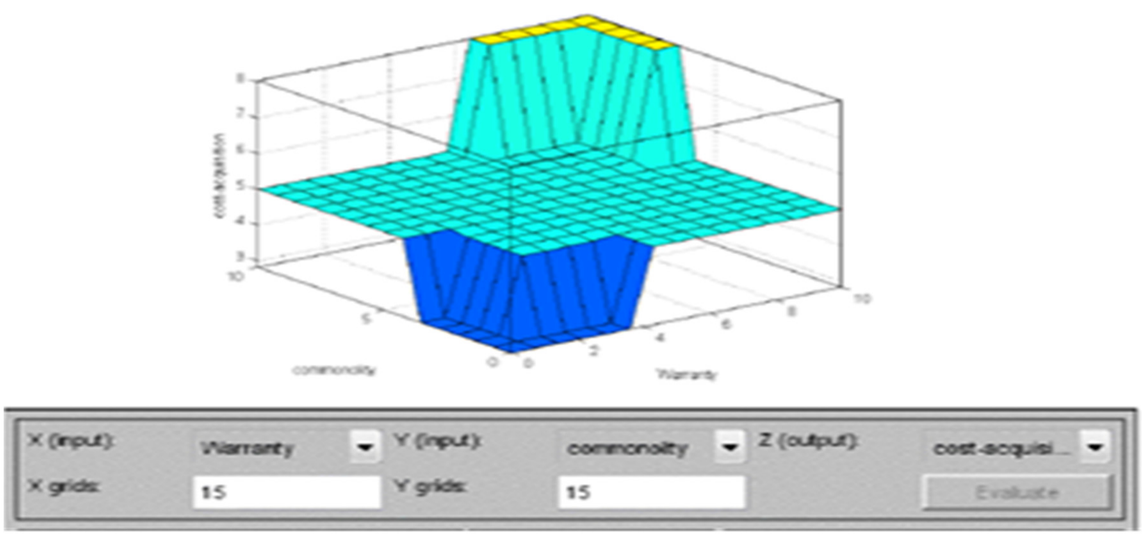


Figure 33 : Acquisition costs related to warranty and commonality of parts

3.2.6.3. The overall model

We utilized Fuzzy Logic Controller blocks in Simulink. We initialized Fuzzy Logic Controller with Rule-viewer block using a fuzzy inference system, which are saved as explained in previous section. The model is illustrated in Figure 34.

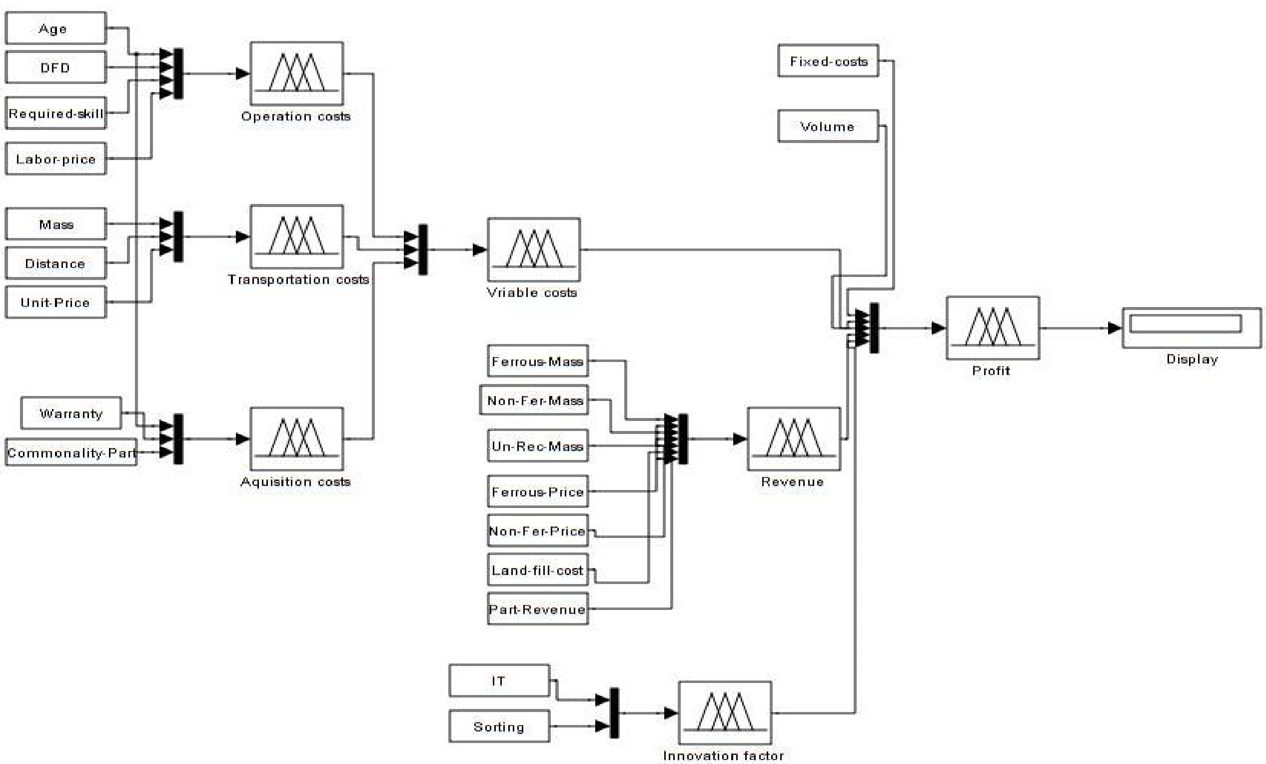


Figure 34 : The model in Simulink

3.2.6.4. User interface

Two screens have been designed for users in order to perform the sensitivity analysis and experimental design. The first screen as shown in Figure 35 gives the users this opportunity to observe the profit variation with altering market variables, technology variables, regulation and auto manufacturer design variables. In the second screen as shown in Figure 36, the user can choose the parameters in order to do full factorial or fractional factorial design analysis.

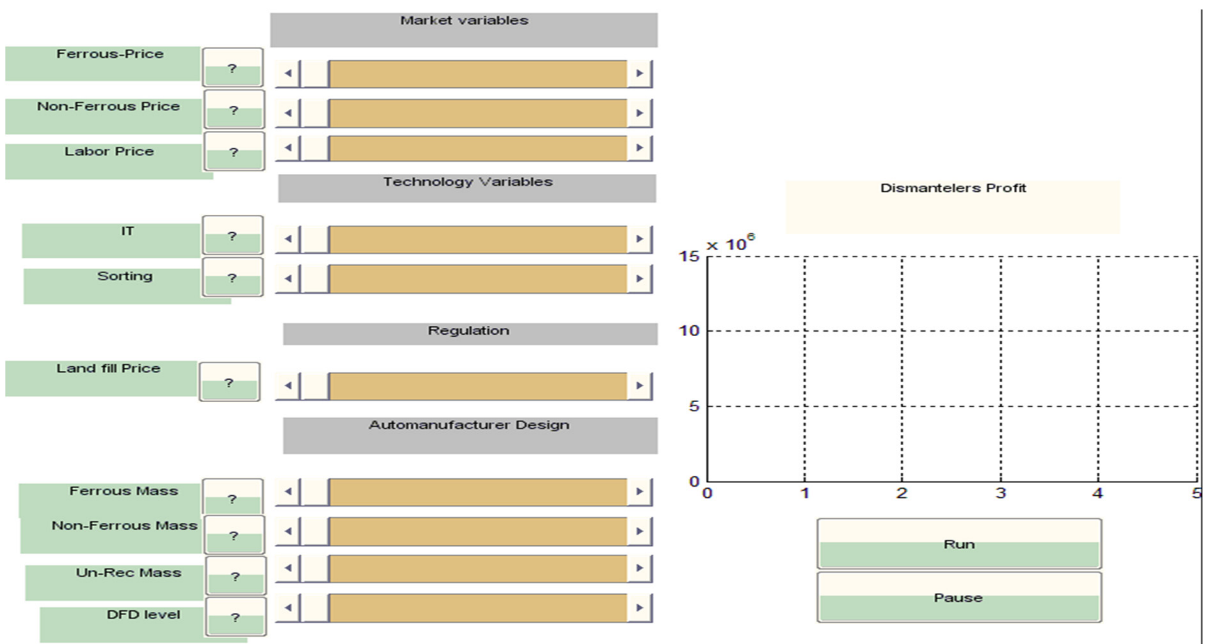


Figure 35 : User interface (Part A)

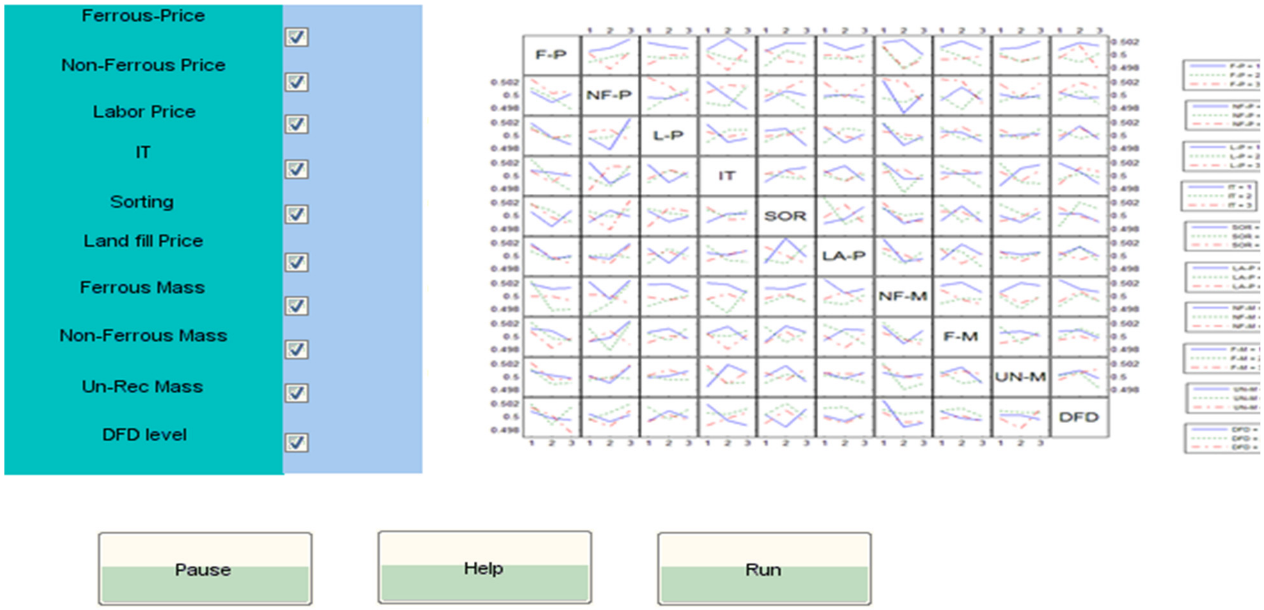


Figure 36 : User interface (Part B)

3.2.7. Conclusion and future works

With increasing attention to sustainable development, developing a decision support tool in order to evaluate the effects of different source of uncertainties in ELV recycling infrastructure is essential particularly for main players such as dismantlers, shredders, and non-ferrous processors. This paper provides an application of fuzzy rule based model to evaluate the economic sustainability of dismantlers in different scenarios as the result of combination of change in market variables, regulation or technology. This framework with considering the uncertainties of variables and the variety of external and internal factors which affect the profit of this business can provide a user-friendly model. This model facilitates the decision making process for dismantlers which are key players in automobile recycling infrastructure. However, the introduced approach in this paper can be applied for shredders and nonferrous processors. Application of this model for other players in recycling infrastructure such as shredders and non-ferrous processors are also conducted by authors and will be published as a separate study.

References

[1] Kanari,N., Pineau, J.-L. and Shallari, S. (2003) End-of-Life Vehicle Recycling in the European Union,Journal of the Material, pp. 15-19

[2] Konz, R. J., (2009) the End-of-Life Vehicle (ELV) Directive: The Road to Responsible Disposal, 18 Minn.J. Int'l L. 431

[3] Kumar, V. and Sutherland, J.W. (2008) 'Sustainability of the automotive recycling infrastructure: review of current research and identification of future challenges', Int. J. Sustainable Manufacturing, Vol. 1, Nos.1/2, pp.145–167.

[4] Staudinger, J.& Keoleian,G., (2001)," Management of End-of Life Vehicles (ELVs) in the US" ,a report of the Center for Sustainable Systems,Report No. CSS01-01

[5] Zamudio-Ramirez,P. (1996) Economics of automobile recycling, Master thesis, MIT

[6] Ferra˜o .P. and , Amaral,J., (2006), Assessing the economics of auto recycling activities in relation to European Union Directive on end of life vehicles, Technological Forecasting & Social Change 73, pp. 277–289

[7] Bandivadekar, A. P., Kumar,V., Gunter, K. L., and Sutherland, J. W. (2004) A Model for Material Flows and Economic Exchanges Within the U.S. Automotive Life Cycle Chain, Journal of manufacturing system, Vol.23/No.1,pp. 22-29

[8] Kumar,V. and Sutherland, J.W. (2010) 'Development and assessment of strategies to ensure economic sustainability of the U.S. automotive recovery infrastructure, Resources, Conservation and Recycling 53, pp.470–477

[9] Ganesh, (2008), Introduction to Fuzzy sets and Fuzzy logic, Prentice- hall.

[10] Yuan, F., (2009), The use of a fuzzy logic-based system in cost-volume-profit analysis under uncertainty, Expert Systems with Applications,, Volume 36, Issue 2, Part 1, March 2009, pp. 1155–1163

[11] Maloo, M. C. (1991). A practical approach for incorporating uncertainty in the conventional cost-volume-profit model. Akron Business and Economic Review, 22(4), 29–40.

[12] Lukasiewicz, J. (1970). Philosophical remarks on many-valued systems of prepositional logic reprinted in selected works. Amsterdam: North-Holland (pp. 153–179).

4. Chapter Four

Value creation & strategic manufacturing

This chapter is dedicated to the following articles:

"End of life Aircrafts Recovery and Green Supply Chain (Opportunities and Challenges)" has been published in the proceedings of International conference of Green supply chain, Arras France, 2014

"Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network" has been published in SAE International Journal of Materials & Manufacturing 7.1 (2014): 73-83.

An extended version of this article is provided here to give more details regarding the study.

"Auto manufacturers and applying green practices (The case of End of life Vehicles) has been published in Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management Bali, Indonesia, 2014

"Sustainable Approach to Aircraft Maintenance at Design Stage" has been published in the Proceedings of RAMS 2014: The annual reliability and maintainability symposium, Colorado, 2014

The titles, figures and mathematical formulations have been revised to the keep the consistency through the thesis.

4.1. End of life Aircrafts Recovery and Green Supply Chain (Opportunities and Challenges)

4.1.1. Résumé

Avec l'augmentation de l'importance du développement durable, l'insertion des préoccupations environnementales dans la chaîne d'approvisionnement est devenue cruciale pour les producteurs. En plus de la consommation de carburant, les constructeurs aéronautiques ont besoin de se soucier de l'impact de l'empreinte écologique des avions en fin de vie. Considérant les défis de recyclage des avions, ainsi que les pratiques et les solutions pour la conception de la logistique inverse dans le cadre des chaînes d'approvisionnements vertes appliquées dans plusieurs secteurs industriels dont notamment l'industrie automobile ne peuvent pas s'adapter à l'industrie aéronautique. Cet article aborde les différents aspects de problème d'avion en fin de vie et leurs effets sur la chaîne d'approvisionnement du fabricant d'origine. Nous proposons un cadre conceptuel avec quatre éléments qui sont : l'offre de compétences de la chaîne, la politique de gouvernance, la relation entre les différents preneurs de décision dans la chaîne d'approvisionnement, et le contexte de l'industrie aéronautique. Ce cadre fournit une base de travail pour évaluer les opportunités et les défis de la chaîne d'logistique verte dans cette industrie. La relation entre les différentes opérations de recyclage des avions en fin de vie et les éléments de la chaîne d'logistique verte est également discutée.

Mots clés: Avions en fin de vie, chaîne d'logistique verte, le contexte d'affaires de l'aéronautique.

4.1.2. Abstract

With growing the importance of sustainable development, inserting environmental concerns in supply chain is crucial for producers. In addition to fuel efficiency, aircraft manufacturers, in greener aviation context, need to care about the foot print of planes at the end of life. Considering the challenges in recycling aircrafts, the practices and solutions for designing reverse logistics and green supply chain for the automotive industry or other industrial sections cannot be applied in the aerospace industry. This paper addresses the different aspects of EOL aircraft problem and their effects on original manufacturer's supply chain. A conceptual framework with four elements; Supply chain Competency, Governance policy, Relationship in supply chain and Aerospace industry context provides a basis for assessing the opportunities and challenges of green supply chain in this industry. The relationship between different operations of recycling EOL aircrafts and green supply chain elements is also described.

Key words*:* End of Life Aircrafts, Green supply chain, Aerospace business context,

4.1.3. Introduction

There are several factors which involved in the complexity of business issues in aviation industry including the role and action of government, absence of normal competition in order to balance the supply and demand, lifecycle of products and important equipment such as engines, aftermarket sales, spare part and maintenance markets, intricate relationship between original manufacturers and upstream value chain partners for risk mitigation and other macro-economic factors such as oil price volatility [1]. Manufacturers in aerospace industry reveal their efforts to achieve the sustainable development in annual environment or sustainability reports. These accomplishments can be summarized in developing the pioneering ways to address global issue of climate change and the effective technologies for reducing the environmental impacts [2]. The ecological impacts of retired aircrafts need to be taken into account in order to have an integrating environmental thinking to the whole product life cycle.

Incorporating environmental thinking into supply chain management including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life is considered and defined as a green supply chain [3]. There are several studies which address green supply chain and closed loop supply chain in different industries. For example, [4] develops a structural model of the barriers to implement green supply chain in Indian automobile industry. Implementation of green supply chain management in Taiwanese electronic industry is studied in [5]. The study of drivers and pressures of green supply chain in automotive industry via an empirical analysis of 89 automotive enterprises within China is conducted in [6]. The study [7] addresses the operational performance of green partnership in supply chain using the data from a survey of the Canadian and United States package printing industry. The studies [8], [9] also with considering end-of-life vehicle (ELV), analyzed establishing closed loop supply chain in Germany and Mexico respectively. In the literature, there is a gap for studying the green supply chain or closed loop supply chain in aerospace industry. Particularly considering the growing number of planes at the EOL, the need of a study to address different opportunities and challenges of aircraft manufacturers with respect to retired aircrafts as a part of product responsibility is essential. Based on Boeing's report the potential market for aircraft at the EOL will be nearly 6000 by 2028 and 40% of this market belongs to North America [10]. The solutions to this complex subject must integrate both technical and business aspects. Moreover, the effects of different operations in aircraft recycling on supply chain are an interesting topic for researchers and industry. This paper introduces a framework for addressing EOL aircraft problem in the context of supply chain and probably would be a good introduction in this topic. This paper organizes as follows: part 4.1.2 describes aircraft at the EOL problem and the recycling process, part 4.1.3 review the literature of green supply chain and its related costs and benefits, part 4.1.4 illustrates the relationship between EOL aircraft issues and the green supply chain elements considering the aircraft manufacturer supply chain, part 4.1.5 introduces a framework for assessing the opportunities and challenges of green supply chain in aerospace industry and finally part 4.1.6 concludes with some remarks and an agenda for future research.

4.1.4. Aircrafts at the EOL & Recycling process

What happen when an aircraft reach to its EOL? With this condition, the cost of maintenance and repair will be increased and the legal framework burdens upgrading to fulfill the legislation. Customer satisfaction and reduced fuel consumption are the other aspects of the decision that aircraft operation is no more justifiable. When the owner comes to this decision it faced by several options. After storage time, if the aircraft is worth more than its parts it can be sold to a country with laxer regulation as a flyer [11] cited in [10]. If this option is not valuable the aircraft has to be dismantled, re-use or disposal. There are numerous important components that can be retained before dismantling, recycling or disposal. Engines, landing gears, avionics, and electronic motors are the most common ones. Doors, wings, interiors can be used for training purpose. Recycling the material is the other aspect of EOL solutions. There are four major classes of materials ranging from low cost interior materials to high performance alloys and composites. For old ones the aluminum is main material with a high achievement in recycling technologies but in new ones as the composites are more than 50% of airplane materials the recycling is another challenge that should be addressed [10]. Aerospace original manufacturers have a long history of looking for ways to re-use or recycle aircraft and their components. The two largest airframe manufacturers, Airbus and Boeing, are at the head of research and major projects in this field. Airbus PAMELA project has successfully confirmed that as much as 85 per cent of an aircraft by weight can be recovered for recycling [12].Boeing has taken a leadership role in aircraft life cycle and end-of-service recycling strategies for more than 50 years. Aircraft Fleet Recycling Association, AFRA, is a global consortium of more than 40 companies that provides environmentally responsible options for aging aircraft. This includes maintaining and reselling reliable airplanes and returning them to service. Safe parts recovery, scrapping and recycling services are available for airplanes that cannot be returned to service [13]. Bombardier obtained a dismantling certification from the (AFRA) in 2010. In August 2010, Bombardier Aircraft Services of Charlotte, North Carolina, disassembled 10 CRJ100/200 regional jets for refurbishing useable components for different aircraft companies. They recovered 1,500 reusable parts, including 300 line-replaceable units per jet [14], [15]. The process of aircraft recycling is shown in Figure 37.

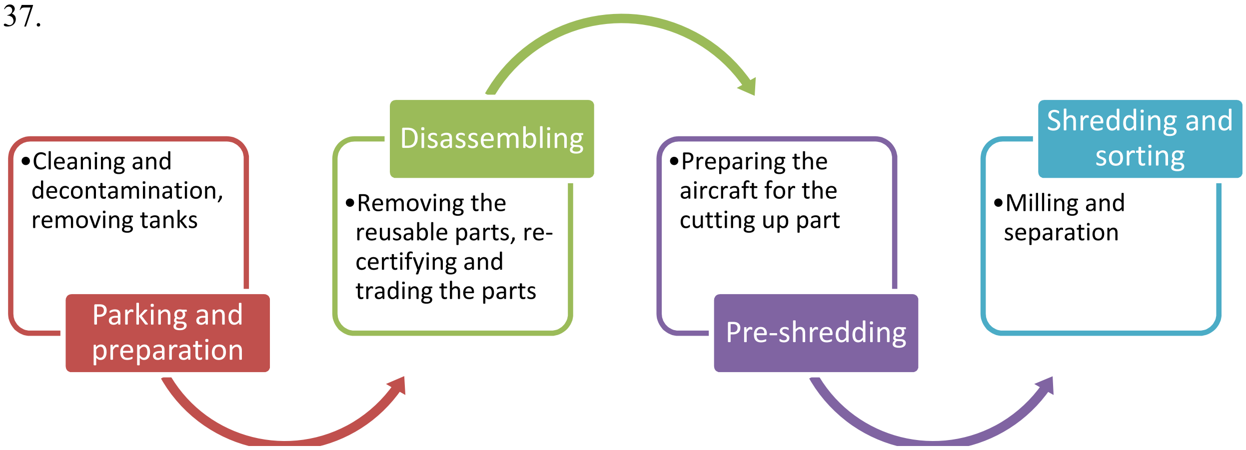


Figure 37 : Aircraft Recycling Process

4.1.5. Green supply chain

The definition of green supply chain varies in literature. As this conception is relatively new areas of study and practice [16], the lack of consent in definition is normal however, based on [17], [18] and [19], we can find the common aspects. Green supply chain is stressing environmental concerns in supply chain management and processes. If we divide the supply chain processes based on the Supply Chain Operations Reference model (SCOR) of the “Supply Chain Council” to source, make, deliver and the equivalent basic scheduling tasks, environmental thinking and performance should be considered in all these activities in order to achieve green supply chain concept. The drivers for green supply chain are including Environmental value drivers, stakeholder interest, Intangible and tangible outcome based on [19], and the results of green supply chain practices are improving agility, increasing adaptability and promoting alignment. These results can be obtained by innovations in processes, continues improvement and better negotiations with suppliers and customers. Based on [20], the key subjects that came out of the green supply chain literature over the last twenty years are the concepts of green design, green operations, reverse logistics, waste management and green manufacturing. However, the author noted that stakeholder’s view towards green supply chain is nearly untouched and should be studied in future researches. The topics related to the green supply chains and their management were also studied based on four major functions [16].These functions included purchasing and in-bound logistics, production, distribution and out-bound logistics, and reverse logistics. The authors stressed that there are only a few empirical researches in this field and the majority of literature are descriptive, anecdotal, and/or prescriptive and studied just small portions of the entire supply chain. It seems that applying green practices on all functions and processes of supply chain is a challenging issue for manufacturers, particularly in some industries.

The other study, [3] provided a state of the art literature review in green supply chain and the author classified the literature based on problem context in supply chain design as well as mathematical tools or techniques. Few studies considered environmental sustainability practices which improved environmental and operational performance as well as significant economic performance because it needs to focus especially on external relationships [21]. Much research is needed to have an integrated study considering internal and external factors including industry context, multiple stakeholder and market analysis for automotive or aerospace industries. Methods for defining an effective green supply chain management are new and are not mature. But organizations can successfully and efficiently “green” the supply chain by incorporating existing environmental standards and innovation uses of new materials and new manufacturing processes [22]. In addition to ecological performance, the green supply chain can lead to competitiveness by engaging in such environmental performance-enhancing activities [23]. This competitiveness can achieved by improving the effectiveness of materials management, the processes that support the cycle of material flows from purchasing and internal control of production materials, through planning and controlling work in process, to warehousing, shipping, and distributing finished products. The competitive advantage of implementation green supply chain based on reference [23] is illustrated in Figure 38. The other advantages can be attained through cost effectiveness of innovation processes of green supply chain approach. The result of green innovation processes related to EOL products in different industries is shown in 39.

4.1.6. EOL aircraft and green supply chain elements

We assumed the management process of aircraft EOL planned to be done by aircraft manufacturer. Therefore, the solution practiced by Airbus in PAMELA project is selected as a basis for identifying these operations. After identification the key operations in aircraft EOL problem, we addressed the relationship between the green supply chain elements and these operations. The nature of Aerospace industry and its market should be considered for analysis the supply chain structure of aircraft manufacturers. In addition we need to assess the problem context.

4.1.6.1. The level of analysis

For supply chain context analysis, clear picture of the structure, modeling and evaluation tools as wells as performance measurement is necessary. Starting every improvement process needs a detailed analysis of operations and processes. In supply chain context, we have four streams including downstream, mid-stream, upstream and reverse stream functions. There are also three main flows including material, information and cash flows. Figure 40 shows the level of analysis. In order to have an integrated approach to EOL aircraft in green supply chain, we need to consider both value and operational views.

Figure 38 : Green supply chain competitive advantages

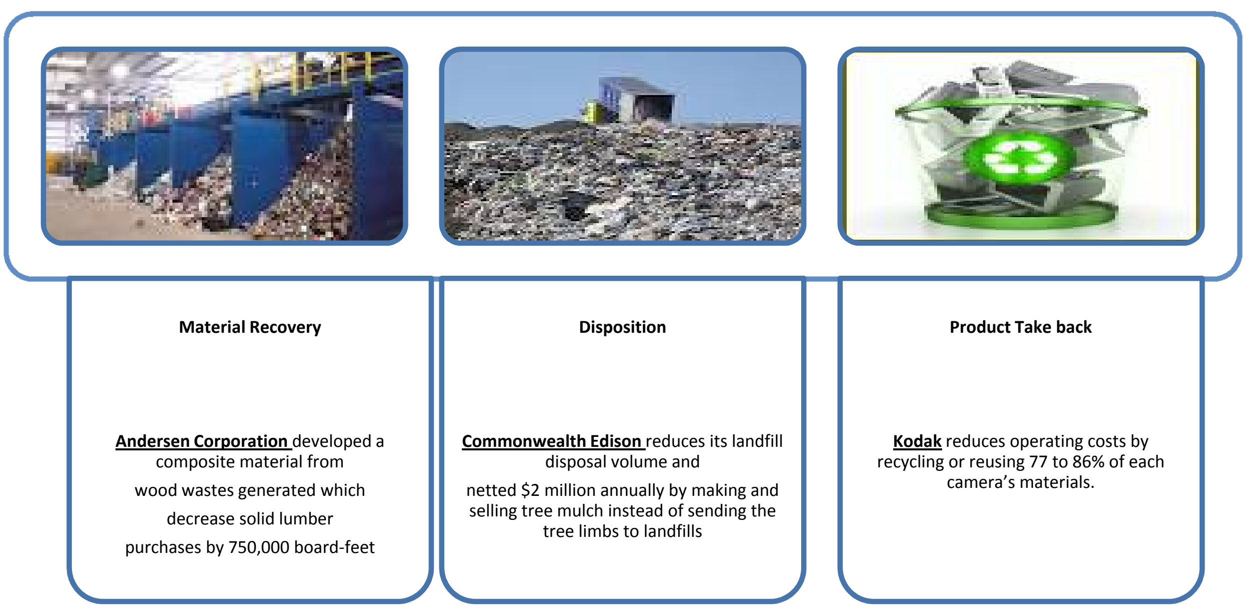


Figure 39 : The result of green innovation processes related to EOL products in different industry (source of information [23])

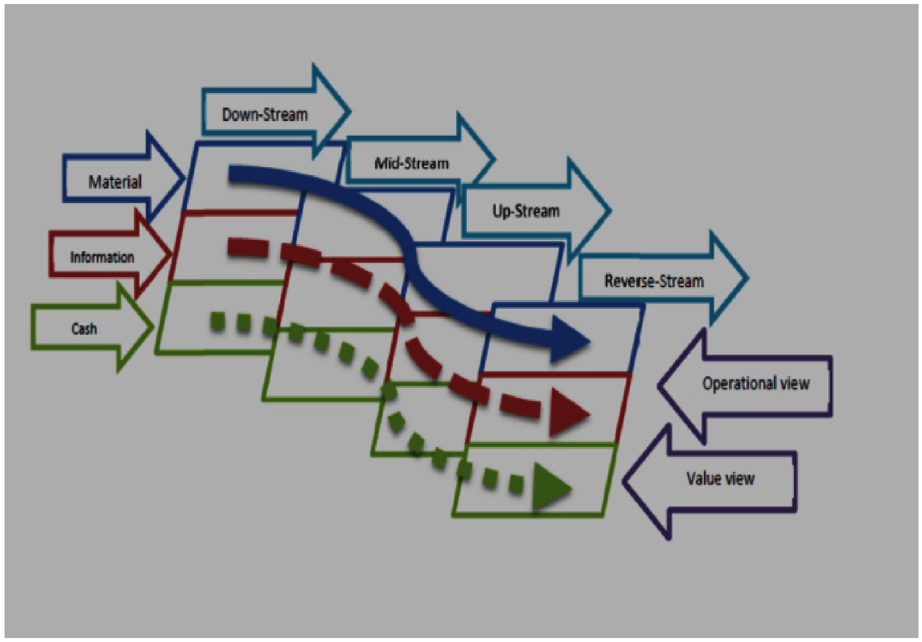


Figure 40 : The level of analysis in supply chain context (adapted from [24])

4.1.6.2. Supply chain in aerospace industry

The Aerospace industry is led by a few large companies. The players such as Boeing and Airbus have important roles in this industry [25]. The practices and processes which have been developed in these large companies can be a guideline or standard processes for other manufacturers in this industry. In addition these practices can clarify and demonstrate the different aspects of the problem. In aerospace supply chain, the large players are supported by a vast supplier base globally, including General Electric Aircraft Engines (GEAE), Rolls-Royce, Honeywell and Pratt & Whitney. They are referred to as tier-one suppliers, and have an important role in the aerospace industry. Tier 1 suppliers are supplied by a large base of tier 2 and tier 3 suppliers, which serve multiple industries (such as industrial manufacturing or automotive). The tier 2 suppliers include companies such as L-3Communications, Harris or Parker-Hannifin. These are followed by tier 3 suppliers which include suppliers of machined components such as castings and raw materials suppliers for metals and rubber [25]. Figure 41 illustrates the different parts of this supply chain based on the Airbus supply chain [26] and the basic structure of supply chain in aerospace industry which provided by [25]. The first tier, the main contractor, does the platform assembly and the large scale integration. Generally, the aircraft manufacturer does these activities by itself. Tier 2 includes the aircraft manufacturer and other suppliers for performing value added parts and assemblies. Other activities for assemblies and providing the raw materials have been done by suppliers in tier 3. The overall interaction between suppliers based on [Tiwari, (2005] shown in the Figure 41. Now with knowing the structure of supply chain for aircraft manufacturer, we can select the key element in green supply chain and show the relationship between the operational processes in aircraft EOL problem and these elements and finally explain that how these activities affect the different parts of aircraft supply chain.

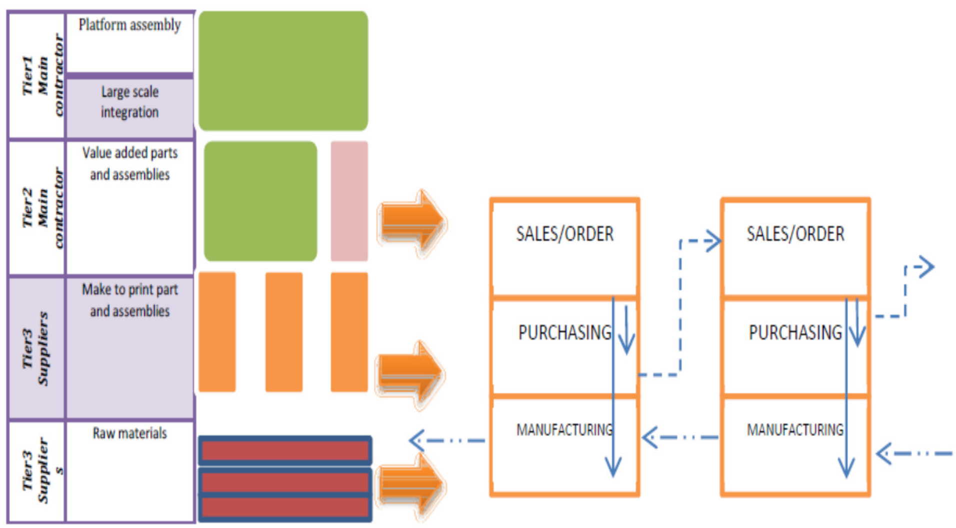


Figure 41: The overall interaction among suppliers in aircraft supply chain (adapted from [25, 26])

Study [3] provides a classification of green supply chain management based on problem context. We adapted this classification to show the relationship between different processes in aircraft EOL problem and green supply chain issues. Green design includes lifecycle assessment of product and process as well as eco design matters. Green operations involve all operational aspects related to reverse logistics (collection; inspection/sorting; pre-processing), green manufacturing and remanufacturing (reduce; recycle; inventory management; remanufacturing: re-use, product and material recovery) and waste management (source reduction; pollution prevention; disposal). The elements of aircraft EOL process have been derived from literature review and the advanced management process of aircraft EOL problem (PAMELA project) report [27]. Figure 43 shows this relationship in a simple way. Based on supply chain structure of airframe manufacturers which is illustrated above, the tiers which may affected by EOL operations has been shown for each sub process. If the operational process is related to a tier, that tier has been colored.

4.1.7. Opportunities and challenges

As described before, there are several issues which need to be considered in implementation of the green supply chain for aircraft manufacturers. In the framework of EOL aircraft recycling and recovery and applying the closed loop supply chain, there are different challenges that should be addressed properly. First of all, the volume of the recovered material from recycling of the aircraft is a small niche of business in comparison of the recovered material in the automotive industry. Hence, it’s difficult to dedicate the supply chain for recovery of this small portion [27]. The second issue is the quality of recovered materials from recycling process. Safety issues in the aviation industry are crucial and cannot be compromised with cost efficiency objectives. Therefore, in this case, down cycling is appropriate. Dealing in second hand part market is a challenging business [11]. There are a lot of associated regulation such as Civil Aviation Authority which should be strictly followed in re-using and recertifying of the components. Furthermore, there are some characteristics in the aerospace industry and supply chain contextual relationship which should be addressed in order to analyse the opportunities and challenges. The conceptual framework illustrated in Figure 42 proposed to address these features and related pros and cons for applying green supply chain in a theoretical basis.

4.1.7.1. Theoretical basis

Organizational theory is in the initial parts operations management and supply chain management literature [28]. Reference [29] provides an overview of a number of organizational theories that have seen applications in the emerging green supply chain literature. Moreover, there are different studies which analyze and evaluate the supply chain management issues in aerospace industry [30], [31], [32]. Based on this literature review, we propose a framework for addressing the different aspects of applying green supply chain in aerospace industry. We utilized 7 organizational theories including resource based view, ecological modernization, corporate governance, complexity theory, stakeholder theory, dependence theory and institutional theory for driving the elements of conceptual framework.

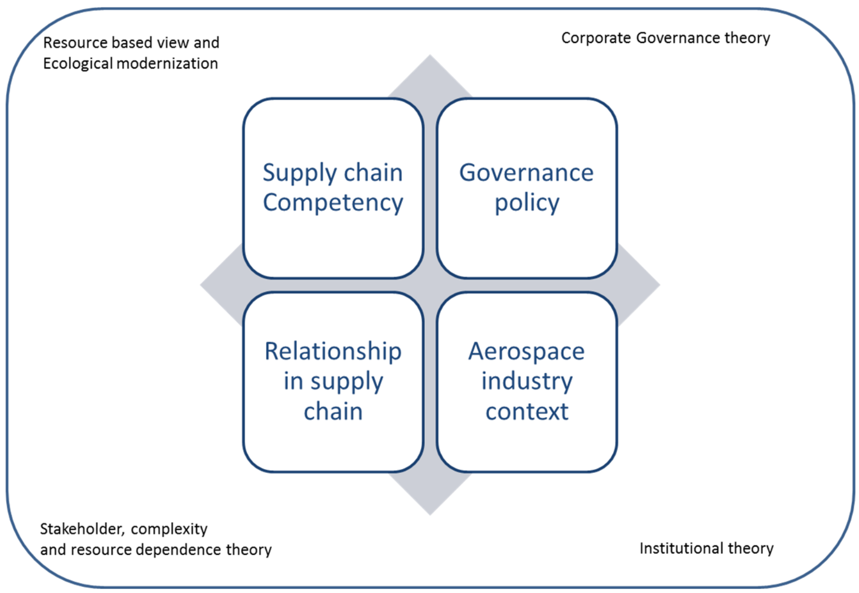


Figure 42 : The conceptual framework and theoretical basis for addressing challenges and opportunities

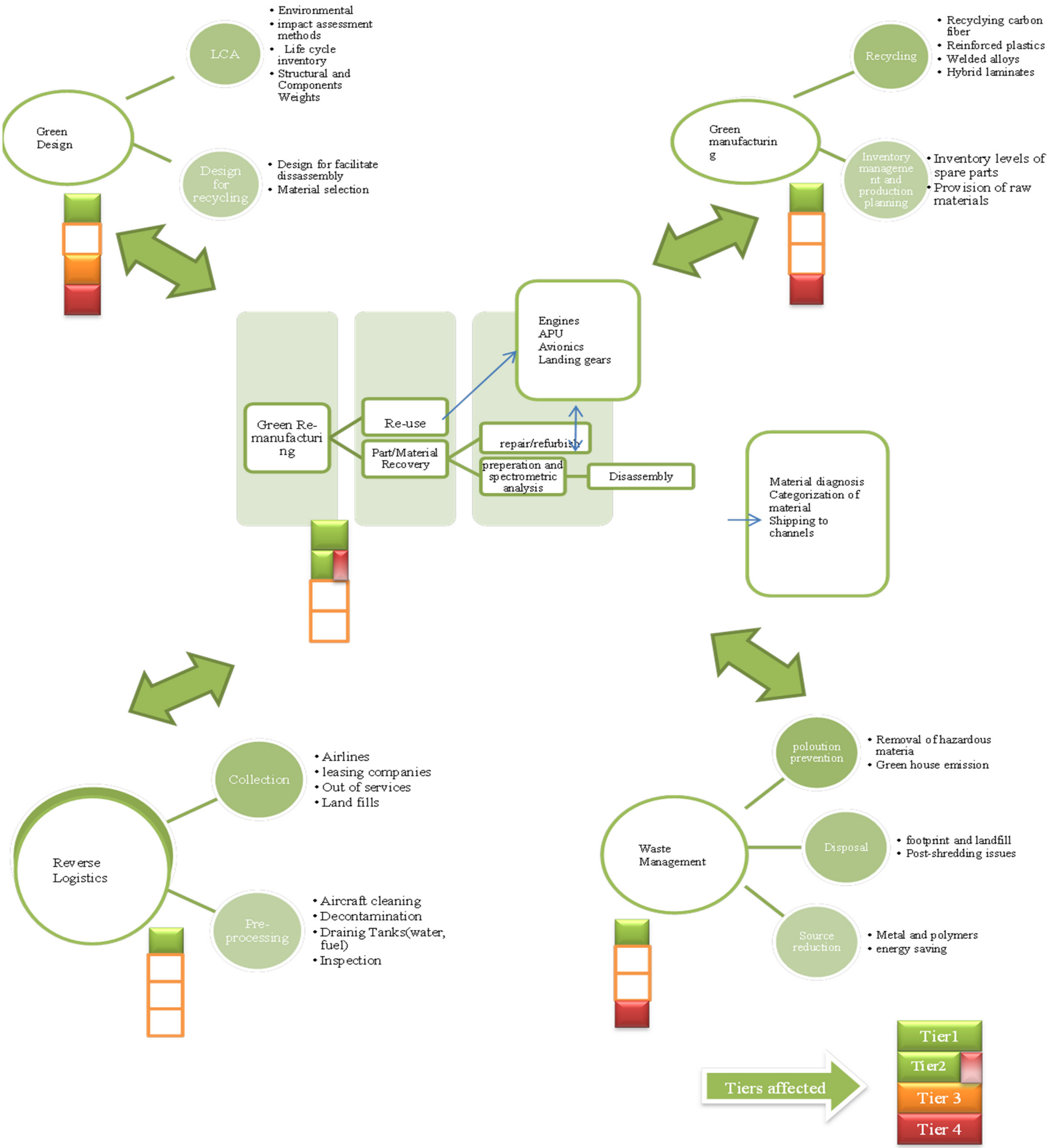


Figure 43 : The relation between Aircraft EOL operation & Green supply chain operational

4.1.7.2. Supply chain Competency

The resource-based model of competitive advantage proposes that competitive advantage may be sustained by binding resources that are valuable, exceptional, imperfectly imitable, and non-substitutable [33], [29]. The essential elements of supply chain in the context of competitive advantages is shown in Figure 44.The supply chain in aerospace industry needs more innovation and flexibility to integrate evolving technologies over the system's life. In addition, constructing collaborative partnerships between manufacturers and suppliers is needed in order to capture significant opportunities in competitive advantage [34]. According to [35], [36], [37], cited in [4] the cost pressure of green supply chain is higher than conventional supply chain but the flexibility and speed of it is lower. Therefore, considering these outcomes, apply green supply chain is challenging. At the other side, implementation of green policies is important for sustainable manufacturers. Ecological modernization theory is geared towards jointly achieving industrial development and environmental protection through innovation and technological development [29]. With growing attention to sustainable development and reducing product foot print, aircraft manufacturers seek innovative ways to improve ecological performance of supply chain. Hence, these two opposite aspects need to be considered.

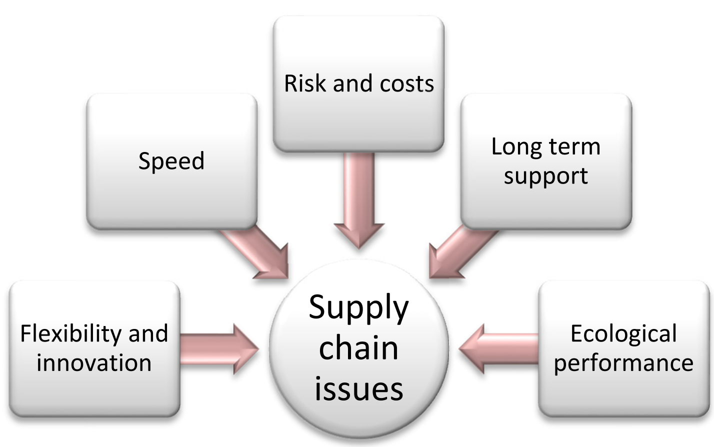


Figure 44 : The essential elements of supply chain in the context of competitive advantages

4.1.7.3. Governance policy

Corporate governance theory suggests the system by which corporations are directed and controlled [40]. The distribution of right and responsibilities among different players is the subject of corporate governance theory. According to [34], "The best governance structures provide clear responsibilities, accountability and integrated performance metrics, while recognizing they cannot be entirely dictated by the prime. Collectively, these structures must drive system cost, schedule adherence and performance, and create individual and collective accountability for end-product results. They must also recognize that the degree of commitment and ownership may vary widely among participants." This reference, introduce two main categories of suppliers for identifying the suppliers of aircraft manufacturers and their relationship. These categories: transactional supplier or customer and fully integrated strategic partner are the extremes of the spectrum of the suppliers of aircraft manufacturers. The prime integrators are those suppliers that have strong relationship with manufacturers while the tier three includes the suppliers with only buy-sell relationship. Green supply chain needs building robust collaborative agreements among suppliers and manufactures. However the managing and governance of this network is problematic in reality. Figure 45 illustrates the place of suppliers for aircraft manufacturers. Designing an appropriate governance policy considering the place of suppliers in the context of green supply chain arise challenges for manufacturers.

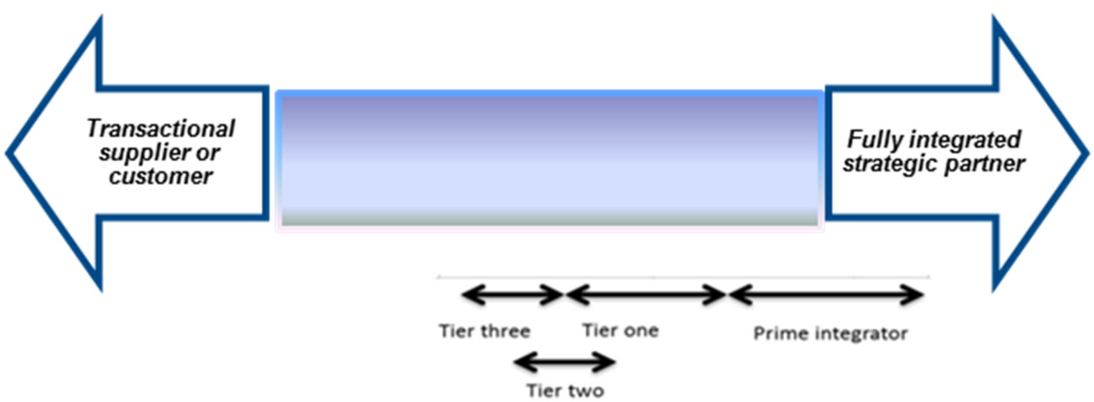


Figure 45 : Suppliers and governance policy challenges adopted from [34]

4.1.7.4. Relationship in supply chain

We discuss three theories in this part in order to show the complex and multifaceted relationship in aerospace supply chain. According to complexity theory as complexity surges firms find it more difficult to plan and predict their organizational actions. Hence, it is essential for firms to be responsive to their environments [38], [29]. There are some difficulties in implementation of green practices and particularly designing closed loop supply chain. The size and relationship in aerospace supply chain can exacerbate this complexity. Stakeholder theory emphasizes that companies need to consider the effect of their actions on the group of the stakeholders. Not only suppliers as the main stakeholder in implementation of green supply chain, but also the other internal and external stakeholders need to be identified and the impact of manufacturer's strategies on them need to be assessed [10],[2]. The other theory, resource dependence theory proposes that in the supply chain, member firms should depend and cooperate to find higher performance advantages in the long-run instead of pursuing short-term benefits at the expense of others [29]. The supplier relationship is an important element in order to reduce the associated risk and uncertainty of green practices. In a global supply chain, the lack of visibility, integration and complexity far upstream can demonstrate as troublesome as problems with a high-tech, advanced downstream participant [34]. Hence, the relationship with downstream and upstream suppliers is a challenging issue. The type of the relationship is also complex. According to [34] in aerospace industry, "One organization might be buying from another company, selling to it, selling with it, competing against it, and engaged in a joint product or service relationship—all at the same time. The word "competition," or cooperative competition, sums up these complex relationships".

4.1.7.5. Aerospace industry context

Institutional theory examines how external pressures influence organizational actions [39], [29]. The pressure from government and other external and internal actors can be the source of opportunities and challenges. See the Table 12 for details.

Table 12 : The opportunities and challenges of Green supply chain (GSC) based on aerospace industry characteristics

	Aerospace industry characteristics	Opportunities for GSC	Challenges for GSC
1	The aerospace sector is dominated by large firms	Flexibility in adaptation	Lack of variety of green practices
2	Specialized with high levels of technological expertise	Good Quality of human resources	Resistance to change considering the known best practices
3	Technological expertise is broadly extent in the supply chain	Utilizing technology advancement adaptation	Uncertainty in applying novel practices, which can affect all suppliers
4	The knowledge-intensive nature of the aerospace	Facility in applying Green practices	The complexity of change
5	A complex network of inter-dependency to present substantial barriers to new entrants	The possibility of good collaboration among partners	Resistance to change through the supply chain
6	Collaborative relationships with very few highly classy clients	Awareness of customers to support environmental solutions	Product responsibility
7	Strong element of strategic support in the government˝s relationship	Government support policies	Lack of relevant directives
8	Major trends of merging and collaboration in international aerospace	Facility in applying Green practices	Uncertainty and market competition

4.1.8. Conclusion and future works

The number of planes at the EOL is increasing. Addressing the different aspects of aircraft EOL problem is challenging for aircraft manufacturers. Considering the strict regulation, size of recovered material, difficulties in dealing components and other contextual challenges, the practices and solutions applied for designing reverse logistics and green supply change for automotive industry or other industrial sections cannot be applied in aerospace business context. This paper addresses the opportunities and challenges of applying green supply chain for aircraft manufacturers and analyses the different aspects of aircraft at the EOL in the context of green supply chain. The relationship between different operations of aircraft EOL problem and green supply chain elements is shown. This study provides an introduction to a gap of studies related to the green supply chain in aerospace industry based on organizational theory. Further studies in addition to empirical analysis are proposed as future researches.

References

[1] Buxton, D. et al. (2006) "The Aero-Engine Value Chain Under Future Business Environments: Using Agent-Based Simulation To Understand Dynamic Behaviour , MITIP2006, Budapest

[2] Keivanpour,S., Ait Kadi, D., Mascle Ch, "Sustainable Eco Design Strategy: Developing a Decision Tool for Aircraft Manufacturers to Compare Eco-Design Alternatives Considering Stakeholders Value Network" Proceeding of SAE 2013 AeroTech Congress & Exhibition

[3] Srivastava, S.K. (2007), Green supply-chain management: A state-of the-art literature review, International Journal of Management Reviews, 9(1), 53-80.

[4] Luthra, S., Kumar, V., Kumar, S., & Haleem, A. (2011). Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective. Journal of Industrial Engineering and Management, 4(2), 231-257.

[5] Zhu, Q., Sarkis, J., & Lai, K. H. (2007). Green supply chain management: pressures, practices and performance within the Chinese automobile industry. Journal of Cleaner Production, 15(11), 1041-1052.

[6] Vachon, S., & Klassen, R. D. (2006). Green project partnership in the supply chain: the case of the package printing industry. Journal of Cleaner Production, 14(6), 661-671.

[7] Schultmann, F., Zumkeller, M., & Rentz, O. (2006). Modeling reverse logistic tasks within closed-loop supply chains: An example from the automotive industry. European Journal of Operational Research, 171(3), 1033-1050.

[8] Cruz-Rivera, R., & Ertel, J. (2009). Reverse logistics network design for the collection of end-of-life vehicles in Mexico. European Journal of Operational Research, 196(3), 930-939.

[9] Ferguson, N., & Browne, J. (2001). Issues in end-of-life product recovery and reverse logistics. Production Planning & Control, 12(5), 534-547.

[10] Keivanpour, S., Ait-Kadi, D., & Mascle, C. (2013). Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects A Research Agenda in Transdisciplinary Context. Journal of Management and Sustainability, 3(3)

[11] Heerden,D. and Curran.R,(2010), Value Extraction from End-of-Life Aircraft, Encyclopedia of Aerospace Engineering-Wiley

[12] Watson .M. End of Aircraft Life Initiatives, SBAC Aviation and Environment Briefing Papers, Available at: http://www.sustainableaviation.co.uk/wp-content/uploads/end-of-aircraft-life-initiatives-briefing-paper-11.pdf

[13] Boeing 2010 Environment Report

[14] Asmatulu, E., Overcash, M., & Twomey, J. (2013). Recycling of Aircraft: State of the Art in 2011. Journal of Industrial Engineering, 2013.

[15] Bombardier. Recyclability "End-of-Life Challenges,", 2011, http://csr.bombardier.com/en/products/aerospace-products/ recyclability.

[16] Toke, L. K et al. ,(2010), Green Supply Chain Management; Critical Research and Practices, Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management Dhaka, Bangladesh Volume I: Report

[17] Godfrey, R. (1998). "Ethical purchasing: Developing the supply chain beyond the environment." in GreenerPurchasing: Opportunities and Innovations, edited by T. Russel, Sheffield, England: Greenleaf Publishing: 244-251.

[18] Green, K., B. et al. (1998), Green purchasing and supply policies: Do they improve companies environmental performance?" Supply Chain Management. 3 (2): 89-95.

[19] Lee, H. L. (2004). The triple-A supply chain. Harvard business review, 82(10), 102-113.

[20] Fortes,J. (2009), Green Supply Chain Management: A Literature Review, Otago Management Graduate Review ,Volume 7

[21] Zhu,Q. et al. (2007), Green supply chain management: pressures, practices and performance within the Chinese automobile industry, Journal of Cleaner Production 15, 1041-1052

[22] Hu, T.L., Sheu, J.B. and Huang, K.H. (2002). A reverse logistics cost minimization model for the treatment of hazardous wastes. Transportation Research, Part E: Logistics and Transportation Review, 38, 457–473

[23] The lean and green supply chain, EPA, retrieved from www.epa.gov/ppic/pubs/lean.pdf

[24] William T., (2004), Supply chain architecture: a blueprint for networking the flow of material, information, and cash, CRC press, edition 1.

[25] Tiwari,M. (2005), An Exploration of Supply Chain Management Practices in the Aerospace Industry and in Rolls-Royce,master thesis , Massachusetts Institute of Technology

[26] Cauquil,O. (2010),Procurement situation in Airbus and supply chain policy, Airbus Procurement, presentation in Toulouse

[27] Eco-Efficiency and Sustainability - G9 - ISSUE 1, Process for Advanced Management of End-of-Life of Aircraft, ACADEMY

[28] Ketchen, J.D.J., Hult, G.T.M., 2007. Bridging organization theory and supply chain management: The case of best value supply chains. Journal of Operations Management,25(2), 573-580.

[29] Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. International Journal of Production Economics, 130(1), 1-15.

[30] Pankaj Raj Sinha, Larry E. Whitman, Don Malzahn, (2004) "Methodology to mitigate supplier risk in an aerospace supply chain", Supply Chain Management: An International Journal, Vol. 9 Iss: 2, pp.154 - 168

[31] Haywood, M., & Peck, H. (2003, June). Improving the management of supply chain vulnerability in UK aerospace manufacturing. In Proceedings of the 1st EUROMA/POMs Conference (Vol. 130).

[32] L.M.J. Michaels, (1999) "The making of a lean aerospace supply chain", Supply Chain Management: An International Journal, Vol. 4 Iss: 3, pp.135 - 145

[33] Barney, J.B., 1991. Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99-120.

[34] A.T. Kearney | IntegratedValue Chains in Aerospace andDefense. Retrieved from www.aia-aerospace.org/assets/smc_wp-valuechains.pdf

[35] Beamon, B.M. (1999). Designing the Green Supply Chain. Logistics Information Management, 12(4), 332-342.

[36] Gilbert, S. (2000). Greening supply chain: Enhancing competitiveness through green productivity. Report of the Top Forum on Enhancing Competitiveness through Green Productivity held in the Republic of China, 25-27 May, 2000. ISBN: 92-833-2290-8.

[37] Ho, Johnny C., Shalishali, Maurice K., Tseng T. Liang, & Ang David, S. (2009). Opportunities in Green Supply Chain Management. The Coastal Business Journal, 8(1), 18-31. Electronic copy available at: www.coastal.edu/business/cbj/pdfs/art

[38] Crozier, M., Thoenig, J.-C., 1976. The regulation of complex organized systems. Administrative Science Quarterly, 21(547-570).

[39] Hirsch, P.M., 1975. Organizational effectiveness and the institutional environment.Administrative Science Quarterly, 20(3), 327-344.

[40] Corporate governance, http://en.wikipedia.org/wiki/Corporate_governance

4.2. Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network

4.2.1. Résumé

Cet article présente une nouvelle approche pour comparer les différentes pratiques d'écoconception considérant le réseau de valeur de partenaires. L'outil de décision proposé dans cette étude aide les fabricants à sélectionner un portefeuille de techniques d' écoconception au début de la phase de conception afin de maximiser la valeur perçue par toutes les parties prenantes dans une double approche de cycle de vie, y compris le cycle de vie des produits de l'entreprise ainsi que le cycle de vie physique. Une approche de sélection de portefeuille a été utilisée pour maximiser la valeur du réseau d'intervenants en tenant compte du coût du cycle de vie tout en respectant la diversité des ressources d'allocation des pratiques d'éco conception en fonction des objectifs stratégiques des fabricants. La caractéristique dynamique du réseau à la suite de la mise en œuvre des différentes techniques de conception écologique a également été prise en considération pour évaluer la synergie du réseau. Par conséquent, le cadre élaboré dans cette étude est un moyen efficace pour aider les décideurs à prioriser les techniques d'écoconception et la gestion d'une démarche partagée. Comme application de modèle développé, nous proposons une ligne directrice pour les fabricants afin de sélectionner le meilleur ensemble de la conception pour la gestion des avions en fin de vie en tenant compte des besoins et des attentes de tous les intervenants. Cette directive peut aider l'avionneur à comparer trois catégories d'éco-pratiques, y compris l'utilisation du matériel, la fourniture d'informations et l'emploi de la conception 3R (réduction, réutilisation et recyclage), de considérer les impacts pertinents sur toutes les parties prenantes, en plus de la priorité de l'entreprise dans une perspective de cycle vie.

Mots-clés: techniques d'écoconception, effet synergique, le réseau d’intervenants, création de valeur

4.2.2. Abstract

This paper introduces a novel approach in order to compare different Eco design practices considering the value network of stakeholders. The proposed decision tool framework in this study helps manufactures in early stage of design to select a portfolio of eco design techniques to maximize the value perceived by all stakeholders in a dual life cycle approach including the business product life cycle as well as physical life cycle. A portfolio selection approach has been used to maximize the network value of stakeholders considering the life cycle cost and risk of techniques while satisfying the diversity of allocation resources on eco design practices based on strategic objectives of manufacturers. The dynamic characteristic of stakeholder's network as the result of implementing the different eco design techniques has also been considered in order to evaluate the synergy in stakeholder's network. Therefore the developed framework in this study is an effective way to assist the decision makers in prioritizing eco-design techniques and managing an optimal portfolio of them. As an application of developed model, we proposed a guideline for Aircraft manufacturers in order to select the best set of design for end of life techniques considering all stakeholder's needs and expectations. This guideline can help aircraft manufacturer to compare the variety of eco practices in three categories including material usage, providing information and manual and design for 3R (reducing, re-using and recycling) considering pertinent impacts to all stakeholders in addition to business priority in life cycle perspective.

Keywords: Eco-design techniques, synergistic effect, stakeholder's network, value creation

4.2.3. Introduction

Recently, considerably extensive attention to sustainable development has started becoming a key aspect in aviation industry. Aircraft manufacturers have reacted to this situation and recognized the importance of focusing their efforts to integrate sustainable development policies into their core business strategies. However, the effectiveness and the efficiency of such efforts have been in question because systematic approaches to support such activities are limited (Morimoto and Agouridas, 2009).

Design for environment (DfE) or Eco design strategy is one of these efforts in order to integrate the environmental considerations into product and process design. There are different techniques and practices which can be used by manufacturers in DfE context. Material substitution, design for disassembly, design for recyclability, design for reusability are some of these practices. Each practice may have impacts on one or more stages of product life cycle as well as different effects on stakeholders and value creation framework. In addition to life cycle effects of these techniques and multitude impacts that may affect the stakeholders, covering broad range of outcomes, uncertainty, complexity and feasibility should also be considered in decisions made by manufacturers in Eco design techniques selection process.

Based on the literature review conducted by Handfield et al. (2001), DfE tools and methodologies are required to be more developed. Furthermore the stakeholders, life cycle approach and multi-criteria decision analysis are needed to be considered in an integrated eco design approach (Bovea and Pérez-Belis, 2012). Moreover according to Wheeler et al. (2003), a manufacturer with sustainable organization culture, require to identify not only the stakeholders and their expectations but also interdependencies and synergies in stakeholder's network to maximize the value considering environmental, economic and social requirements. Thus, for sustainable eco design strategy, in addition to considering the value outcomes of implementation an eco-design technique, its impact on stakeholders network is also needed to be taken into account.

In this paper, we developed a decision tool for comparing different eco design techniques using portfolio selection approach. For coverings the value creation concept, we also developed a separate model for analyzing the value perceived by stakeholders as the result of implementation of each eco design practice. Furthermore, we used social networks measures to evaluate its impacts on stakeholder's network. The decision tool framework using portfolio selection, the proposed stakeholder's value model and evaluation of network implications are discussed here respectively.

For selection of appropriate eco design techniques, we have three categories of attributes. There are some independent attributes for implementation of each practice such as the costs and benefits derived from applying this practice. The second attributes are interrelated attributes such as shared resources or shared risks and finally some synergistic attributes such as diversity in life cycles or design stages. As the portfolio selection approach includes these three types of attributes (Chien, 2002) hence, we utilized this approach to select the optimal portfolios of eco design techniques. Furthermore, according to Doerner et al. (2004) decision-makers must consider multiple objectives and regularly have slight preference information. With this limitation they can improve their chances of achieving success by a two-phase approach that first determines the solution space of Pareto-optimal portfolios and then allows them to interactively search that space. There are some reasons that prove the one optimal solution is not sufficient particularly for business problem and industrial applications. Incompleteness of model, linearity of constrains, the approximation of dada and the need of decision makers to have choice are some of these reasons (Emilie Danna et al., 2008). Hence, in this study we used a two phases approach for modeling. In first phase we find the optimal portfolios and then in second phase considering the strategic objectives of manufacturers, network implication and life cycles effects, the best portfolio can be selected.

There are few studies that consider stakeholders in eco design methodology such as Karlsson, (1997), Davidsson, (1998) and Halog et al., (2001). Moreover the literature is not so rich with respect to proposed methods or approaches for analyzing the value perceived by stakeholders. The value of stakeholders in design decision or implementation a new strategy has been taken into account recently. For example, Sutherland, (2009) introduced a stakeholder value loop analysis for space based earth observation. Allee (2008) developed a general methodology for value network analysis including Exchange analysis, Impact analysis and Value creation analysis. Agouridas et al. (2006) proposed a methodology to support the initial analysis of stakeholder needs and attributes, and the derivation of corresponding design requirements.

In comparison, there are more studies which address the value models for customers. Taxonomy in these models and methodologies shows that an integrated approach is needed to use the benefits of each model (Khalifa, 2004). The integrated framework should include value exchange model which addresses the associated costs and benefits for customers, value build-up model which addresses four aspects including the view of relationship, the customer benefits (from tangible to intangible), customer need (utility need from psychics need) and view of customers and dynamic aspect that addresses level of satisfaction of customers as the absence or presence of an attribute. So there is a need for developing a model for analysis the stakeholder's value considering the above aspects. In this study, we developed a model for evaluation of value perceived by stakeholders based on the needs and expectation of stakeholders and their influences on manufacturer and the features of each eco-design practice. Technical, environmental, economic and social features of the practices have been considered in this model.

Social network analysis literature is full of different measures and functions which can be used in order to study the networks. However some of these measures can provide highlights with respect to functionality and efficiency of network. According to (Jackson, 2008) There are two challenges in modeling networks from strategic point of view. Explicitly model the costs and benefits that arise from various networks and how the individual incentives translate into network outcomes. In addition since the sharing information and opinions formation are important characteristics of social networks, how the structure of network can affects learning and information diffusion are needed to be considered in social network analysis. In this study the dynamic characteristic of stakeholder's network as the result of implementing the different eco design techniques has also been considered in order to evaluate the synergy in stakeholder's network.

The structure of the paper is as follows: In section 4.2.2, we review the literature review and highlights points which led to the elements of the model. Section 4.2.3 illustrates the decision tool. In section 4.2.4, we provide a guideline in order to compare the different design for end of life alternatives applicable for aircraft manufacturers. We conclude with a discussion in Section 4.2.5.

4.2.4. Literature review

In this part we provide a framework for conducting the literature review. The synthesis in literature led to the elements of our proposed model. This framework has been illustrated in Figure 46. In eco-design literature part, we focused on definition of eco-design practices, the relevant tools and techniques, the metrics, the concept of value and stakeholders in current studies and the existing gap in order to achieve an integrated approach. In stakeholder's literature, we studied the different methods for analyzing and representation of stakeholders in addition to the concept of value and network analysis in this context. The value network literature covers the different approaches of value analysis including mapping and network analysis. Finally, we provided the literature of portfolio selection including the different methods and its advantages in order to show the capability of this approach for comparing the eco-design practices alternatives. The highlights of literature review have also been described in Figure 46.

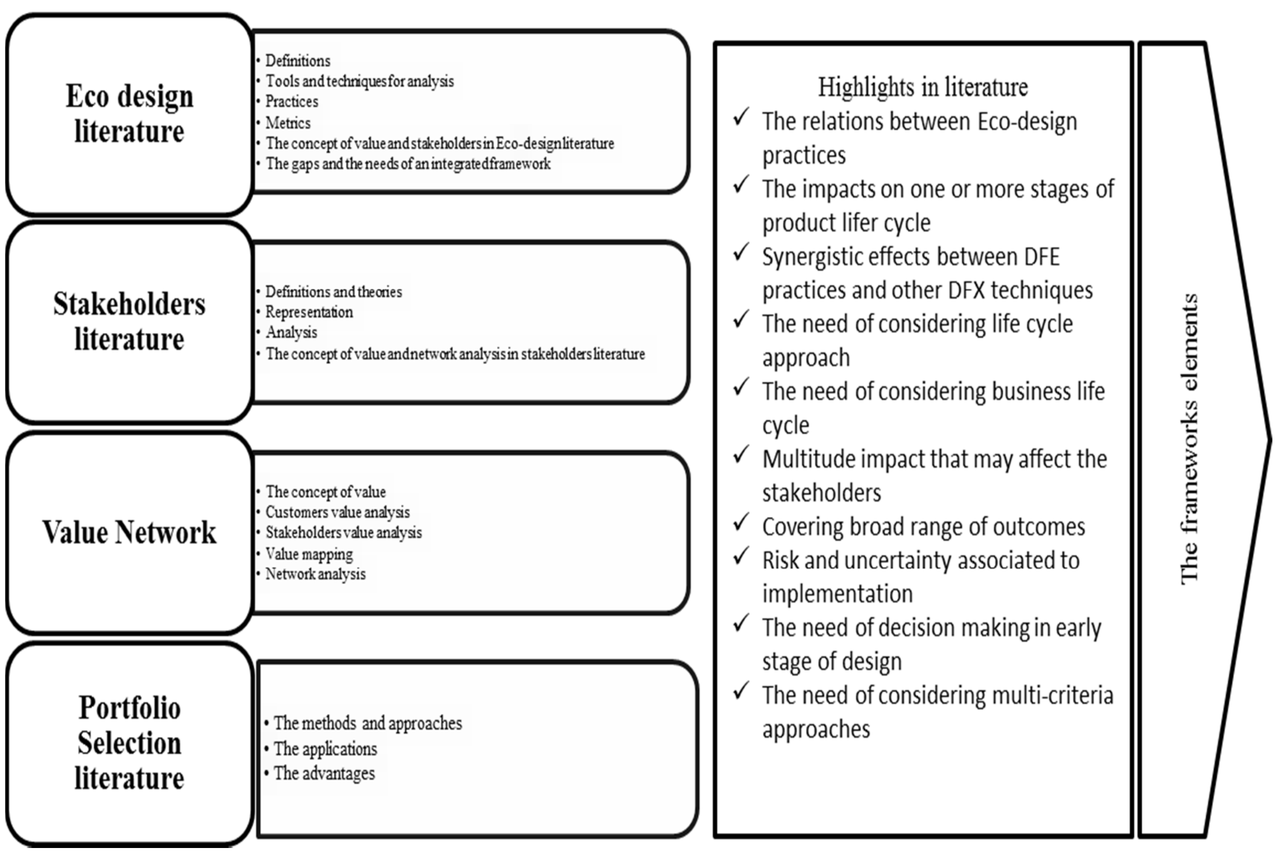


Figure 46 : The framework for conducting the literature review

4.2.4.1. Eco design literature

Today environmental performance is given the same position as the older product values such as profit, functionality, aesthetics, ergonomics, image and quality (Rose, 2001). A complete definition for eco design is provided by (Rose, 2001): "An integral component of the Design for X paradigm, covers all life cycle stages including material extraction, manufacturing, transportation, usage and end-of-life phases. Design for Environment seeks to understand the life cycle of the product and its impact on the environment at each of its life stages and to make better decisions during product design so that environmental attributes of the product are kept at a desired level ". This definition can reflect different aspects of DfE defined by other literature, such as considering the environmental aspects in each stage of the product development process (Van Hemel, 1998) or systematic consideration of design performance with respect to environmental, health and safety objectives over the full product and process life cycle (Boks, 2000). The key elements of DfE according to (Fiksel, 1996) have been illustrated in Figure 47. This figure illustrates that for DfE we need to address the relevant efficiency metrics, identifying the different alternatives and an evaluation approach in order to compare these alternatives.

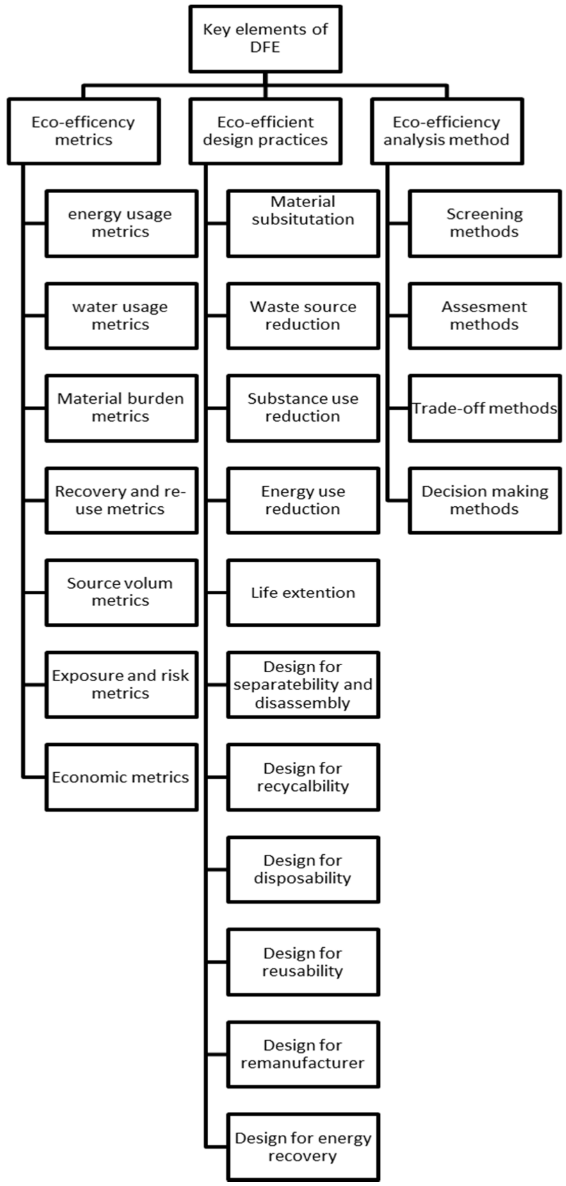


Figure 47 : The key elements of DfE

Handfield et al., (2001) conducted a literature in order to find the gap between theory and practice in DfE context. The authors believe that the related research can be classified in three categories. The first category of research is success stories of companies known for DfE by the press. The second category of research provides engineers and managers guidelines for integrating environmental concerns into the product design process. The third stream of research introduces specific tools to be utilized for DfE process. The authors conclude that DfE tools and methodologies are at a very early stage of development.

Bovea and Pérez-Belis, (2012) provided a taxonomy of eco-design tools for integrating environmental requirements into the product design process. Among the literature reviewed in this study, three studies have considered stakeholders expectations in their model. (Karlsson, 1997) developed an Environmental Objective Deployment model in order to investigate the relationship between environmental considerations and the product design. The life cycle screening matrices in this study conducted for three perspectives (environmental burdens, stakeholder preferences and liabilities). This model is applied to improve the product using the indicators obtained in the initial review, but with a strong emphasis on customer requirements.

Davidsson, (1998) used an ecodesign methodology for product development that combines screening LCA (Life Cycle Assessment) with QFD (Quality Function Deployment). In this methodology, the author utilized a detailed process to obtain stakeholder expectations throughout the product life cycle, which will be introduced in the HoQ (House of Quality) of the QFD method in order to obtain different conceptual design proposals.

Halog et al., (2001) also introduced a methodology with considering stakeholder requirements. They used a modified version of HoQ in this study.

Bovea and Pérez-Belis, (2012) at the end of the study concluded that most of Eco design tools are not applied in a systematic way in companies due to their complexity, the time required to apply them and the lack of environmental knowledge. The authors believe that early integration of environmental aspects into the product design and development process; the life cycle approach, which takes into account how the product can affect the environment in its different stages; and a multi-criteria approach are needed in this context. In the other words an integrated approach includes three essential elements, early integration of environmental aspects into the product design and development process, life cycle approach, which takes into account how the product can affect the environment in its different stages and multi-criteria approach, which simultaneously takes into account all the traditional requirements that affect the product together with the relevant environmental aspects and impacts.

According to this literature DfE tools and methodologies are required to be developed. Moreover the stakeholders, life cycle approach and multi-criteria decision analysis are required to be considered in an integrated eco design methodology.

4.2.4.2. Stakeholder's analysis

The most generally accepted definition of what represents a stakeholder is given by R. Edward Freeman in his landmark book, Strategic Management: A Stakeholder Approach, where he states that "stakeholder is any group or individual who can affect or is affected by the achievement of the firm's objectives"(Bussy and Kelly, 2010). How stakeholders influence the firm and how the firm responds to those influences defined in stakeholder analysis (Rowley, 1997).The framework of the relationship between stakeholders including the orientation and the key issues such as trust and communication discussed in stakeholder relationship (Grossi, 2003). There are also several theories that cover the base for analysis of the stakeholders. The stakeholder's study includes stakeholder's identification, stakeholder's representation and stakeholder's analysis. The stakeholder's identification is the problem of finding the relevant stakeholders who create the value for firms. With respect to complexity of relationship between firms and stakeholders, identification of important stakeholders is difficult task (Grossi, 2003). (Mitchell et al., 1997) proposed a method for classifying stakeholders based on the following attributes: the stakeholder's power to influence the firm, the legitimacy of stakeholder relationship with the firm and the urgency of stakeholders claim on firm. However these attributes are the dynamic attributes which can be changed over time and in different circumstances. The other approach for prioritizing the stakeholder is measuring stakeholder's salience. Mitchell et al., (1997) defined the salience of stakeholder based on the value of each mentioned attributes and the strength or intensity of each one. Hence seven types of stakeholders can be identified which the most important stakeholders will be definitive stakeholders (For more details see Mitchell et al., 1997).

Developing stakeholders map or graphic representation or structure of stakeholder's relationship is essential for stakeholder's analysis. The relationship among stakeholders can be evaluated in a dyadic or network framework. Evidently, the network representation of stakeholder provides more information regarding the interdependency of stakeholders and interactive behaviors among them (Rowley, 1997).

Stakeholder maps are an important component in the visualization and influence comparison necessary for stakeholder analysis. Moreover the idea of using network analysis to understand the context and policy options has become a profitable research direction. The relevant literature addresses surveys of the overall network structure with a view to explaining group behavior and studies which utilize network dynamics to realize the opportunities for an individual player.

Relationship orientation, trust, communication, learning power and commitment are the other variables which can be considered in assessing the stakeholder's relationship (Polonsky et al., 2002). There are different approaches in order to analyze the stakeholder's network. Social network and game theory are two well-known methods for stakeholder's analysis which can be applied according to the objectives of case under study. However sometime, based on the complexity of problem, the combination of these methods is needed for a sound analysis. Social network can be appealed where the sub-groups behavior, visualization of network structure and the flow among stakeholders are considerable. The game theory approach can be applied where the interaction of actors and the value creation by actors under mixed strategies for each player are significant. It should be noted that as we are going to apply the introduced methodology in this study in aviation context and as the current attitude in applying eco-design practices in this industry is more collaborative rather than competitive, we used social network framework and cooperative game principles for developing the proposed methodology.

4.2.4.3. Value network

In this part, first of all we review the concept of value and as the customer's value analysis have been more taken into account in literature; we studied the customer's value models and applied its principles for stakeholder's value analysis. We study the stakeholder's value analysis and then focus on network analysis approaches. According to (Leszinski and Marn, 1997) the concept of value is one of the most stereotyped and misused concepts in social sciences and management. The application of value concepts in different fields such as finance, economics, management, information systems, ethics, aesthetics, social equity and etc. (Normann, 2001; Wikstrom and Normann, 1994) and in different literature such as marketing literature- including, total quality management literature, and strategy indicate the stereotyped aspect of this concept. There are different studies which support the importance of stakeholder's value. Emphasizing on social responsibilities of companies to create value (Barsky, et. al., 1999), the importance of participation of stakeholders in determining the organizational goals (Gomez, 1999; Langtry, 1994) and considering value creation for stakeholders as a purpose of business firm (Normann and Ramırez, 1994) are some of the mentioned studies (Khalifa,2004).

According to (Khalifa, 2004) the customers value models can be classified into three categories: value components models, utilitarian or benefits/costs ratio models, and means-ends models. The value component models are especially useful in thinking about product features in the process of developing new products and/or services. They pay, however, modest attention to the interaction and relationship between customers and suppliers in product/service delivery. They pay much less attention to the full customer activity cycle that spans from need identification through purchase, use and disposal of the product. They also are incomplete in that they focus on customer's benefits and demote the customer's sacrifice side of the value equation. These utilitarian models are broader than the value components models and more complete. They consider customer value in a longer time horizon perspective and include almost all elements of customer activity cycle. However, they do not pay much attention to the dynamics of value building and destruction. They seem to be static rather than dynamic. They do not link benefits and sacrifices with customer ends, values and purposes. They also do not offer much on the importance of different Benefits to prospective customers or the significance of sacrifices, nor they consider explicitly the consequence of all these on customer behavior. The means-ends models of customer value fill a gap in the literature by being able to explain why customers attach different weights to various benefits in evaluating alternative products/services. They also take into account the negative consequences of certain product/service attributes but fail to pay sufficient attention to the sacrifices a customer is likely to bear in acquiring, using, or disposing of the product/service. They also do not elaborate on the trade-offs customers are expected to make between benefits and sacrifices.

Khalifa, (2004) concludes that in order to have an integrated approach to customer's value, we need to use the benefits of each model. Value exchange model addresses the associated costs and benefits for customers. Value build-up model addresses four aspects including the view of relationship, the customer benefits (from tangible to intangible), customer need (utility need from psychics need) and finally view of customers. Dynamic aspect addresses level of satisfaction of stakeholders as the absence or presence of an attribute. Sutherland, (2009) introduced a value network modeling including 11 steps : Define the enterprise project, Identify the stakeholders, Identify stakeholders objectives and needs, Develop stakeholder map, Visualize stakeholder value flow, Characterize the needs and value flows, Quantify the value flows, Calculate value loops, Analyze value loop result, Create a simplified stakeholder map and Derive program goals from the value loop analysis. Allee, (2008) developed a methodology for value network analysis. The first phase of this methodology is mapping the value exchange including the roles of players, the transactions and deliverables. The author believes that for performing a value network analysis we need to implement (1) Exchange analysis – What is the overall pattern of exchanges and value creation in the system as a whole? How healthy is the network and how well is it converting value? (2) Impact analysis – What impact does each value input have on the roles involved in terms of value realization? (3) Value creation analysis – What is the best way to create, extend, and leverage value, either through adding value, extending value to other roles, or converting one type of value to another? (See Allee, 2008 for more details).Social network analysis literature is full of different measures and functions which can be used in order to study the networks. In this literature, three specific categories of literature can be considered. The first category is network representation which demonstrates the preliminary knowledge about the players and their relationship. The second category is strategic formation. According to (Jackson, 2008), there are two challenges in modeling networks from strategic point of view. Explicitly model the costs and benefits that arise from various networks and how the individual incentives translate into network outcomes. These challenges can be discussed in the second category of literature .Third category is network implications. As the sharing information and formation of opinions are important characteristics of social networks how the structure of network can affects learning and information diffusion are considered in this category. Some of key concepts with advantages and limitation of their application in our study are shown in Table 13.

Table 13 : Key measures and concepts in social network study used in this paper

	Measures		Definition and references	Advantages /Limitation for applying in our study
Stakeholders network representation	Network	Density	The number of relationship between stakeholders with respect to total possible number of links (Grossi, 2003),(Jackson, 2008)	As this index cannot be a measure of functional efficiency of network, it needs to be applied with the other measures.
		Cohesiveness and clustering	It measures how cohesive or closely knit a network is (Jackson, 2008)	It can help to demonstrate how network tightly clustered. It can be applied to determine the forming innovation and technology clusters or some cooperative clusters via implementing the Eco design practices.
	Nodes	Degree	It measures the number of relationships or links which each stakeholders maintain in the network or nodes neighbors (Grossi, 2003),(Jackson, 2008)	This measure can be applied in some sub-groups or for interested players.
		Centrality	There are different indexes for measuring centrality in the network. In general this index show which stakeholders are more important in the network. Degree centrality, closeness and betweenness are indexes in this category. (Grossi, 2003), (Jackson, 2008)	Centrality can be used as a measure of functional complexity of network. Particularly when we want to measure the communication complexity of stakeholder's network.
Strategic stakeholders network formation	Incentive of players and resulted network outcome	Utility for each player in network	The utility of player or pay-off player represent the net benefit that a player receives in a particular network. The costs and benefits of interaction and different types of allocation rule (player based or linked based) are discussed in this part. (Jackson, 2008)	As we need to assess value added of different network structure in case of applying different practices, this concept can determine the benefit of applying Eco design practices from strategic network perspective.
		Stability of network	With respect to a certain allocation rule, this measure can determine how much one player has the discretion to unilaterally terminate relationship which he or she involved. Pairwise stability and strong stability are indexes which can be applied for measuring the stability of networks. (Jackson, 2008), (Demange and Wooders, 2006)	The stability of network measure can be helpful in case of applying some certain Eco design practices. This matter shows that which portfolio of practices can lead to more stable stakeholder's network. However as the pairwise stability only considers a single link at a time, it cannot measure the advantages of adding or deleting several links simultaneously. (Jackson, 2008)
	Overall value generated	Efficiency of network	This measure evaluates the forming of best network that maximizes the total utility of all players in the	Similar to stability of network, the efficiency of network measure can be helpful in case of

	by network		network. Efficient or Pareto efficient can be applied for evaluating the network efficiency (Jackson, 2008), (Demange and Wooders, 2006)	applying some certain Eco design practices. This matter shows that which portfolio of practices can lead to more efficient stakeholder's network.
	Decisions and behaviors of players	Cooperative game	A cooperative game is a game where groups of players may impose cooperative behaviour; hence the game is a competition between combinations of players, rather than between individual players (Driessen, 1988)	This approach can be used in order to evaluate the value splitting among players in different network structure.
		Non-cooperative game	A non-cooperative game is a game in which players make decisions individually.	This approach can be used in order to focus on behavior of some players (for example manufacturers and regulation bodies, or manufacturers and competitors) however in order to present the network value, this approach has some limitations.
Stakeholders network implication	Diffusion of information and Learning	Influence	This measure determines Which players have the most influence over the opinions (Jackson, 2008)	As the communities and media are important stakeholders, these measures can determine most influential players and the structure which lead to a convergence of opinions more quickly.
		Convergence	This measure determines How quickly players learn and how the information can be aggregated in the network (Jackson, 2008)	

4.2.4.4. Portfolio selection

In the case of selecting R&D projects, the decision makers need to determine which new proposals should be selected, which existing should be continued and how much budget should be allocated on each new one based on the available resources and associated risk of these projects. From this point of view, the selection of Eco design practices can be compared with R&D projects. The literature shows that the portfolio selection has been applied in different contexts particularly in the context of research & development (R&D). The taxonomy of portfolio attributes (Chien, 2002) identifies three types of portfolio attributes. Independent portfolio attributes which measure the related project attributes such as costs and value of each project. Interrelated portfolio attributes that address the interrelated contribution of the projects such as shared costs and risks. The third attributes are the synergistic portfolio attributes which can be applied when considering the preference among alternative portfolios such as geographical diversification of selected projects (Hall et al., 1992). For selection of appropriate eco design practices we have also these three categories of attributes. There are some independent attributes for implementing of each practice such as the costs and benefits derived from applying these attributes. The second attributes are interrelated attributes such as shared resources or shared risks and finally some synergistic attributes such as diversity in life cycles or design stages. Hence the portfolio selection is an appropriate approach in order to be applied in this study.

Different tools and solutions can be used for solving these problems. Table 14 shows the variety of approaches utilized for portfolio selections. We used a two phases approach in order to evaluate the portfolio as whole and also each Eco design technique. In first phase, we apply a multi-objective optimization model to select the best practices and in second phase we utilize multi-attribute utility approach to compare the portfolios.

Table 14 : The different approaches used for portfolio selection

Approaches for modeling	References
Multi-objective Pareto Ant Colony Optimization	Doerner et al. (2004)
Multi-objective particle swarm optimization	Rabbani et al.,2010
Mixed 0–1 goal programming	Badri et al.,2001
Goal programming	Mukherjee and Bera (1995)
Multiple criteria decision model	Santhanam and Kyparisis (1995)
Nonlinear 0–1 decision model	Santhanam and Kyparisis (1996)
Linear programming	Hall et al.,(1992)
Decision support system	Dey (2006)
Multi-period linear 0–1 goal programming model	Rabbani et al.,2006
Evolutionary approach	Medaglia, Graves, and Ringuest (2007)
Two-phase method	Mavrotaset al. (2007), (Chien,2002)
Fuzzy mixed-integer programming model	Carlsson et al.,(2007)
MAV/MAU	Golabi et al.,1981, Husseiny (1981)
Mean variance approach	Galligan and Marsh (1988)
Hierarchical framework	Peerenboom et al.,1989
Fuzzy ANP	Mohanty et al.,2005
Balance model	Rao et al.,1991

According to Doerner et al. (2004) decision-makers must consider multiple objectives and regularly have slight preference information. With this limitation they can improve their chances of achieving success by a two-phase approach that first determines the solution space of Pareto-optimal portfolios and then allows them to interactively search that space. There are some reasons that prove the one optimal solution is not sufficient particularly for business problem and industrial applications. Incompleteness of model, linearity of constrains, the approximation of dada and the need of decision makers to have choice are some of these reasons (Emilie Danna et al., 2008). Hence in this study we will use a solving approach for the optimization model in order to determine different optimal solutions and afterward we apply the second layer in decision tool to find the final Eco design portfolio.

4.2.5. The decision tool

The framework of proposed decision tool is shown in Figure 48. The first part of the decision tool is data module. The data from the other design models, economic models and LCA models or other complex system models are far too complex to be linked directly to decision tool. Therefore an interface between the complex system models and the design tools are needed. We used the fuzzy logic concept in order to provide the required data for the decision tool. We named this module expert opinion module. We also developed a separate model in order to calculate the value perceived by each stakeholder as the result of implanting each Eco design practice. The next part of decision tool is portfolio selection module. We developed an optimization model in this part. The optimization model includes the required resources and cost of each practice, the value perceived by stakeholders, the associated risk and the interdependency among practices. After this phase, we considered the synergistic attributes of portfolios via value network analysis, life cycle analysis and strategic decision analysis. We also utilized multi-attribute utility analysis in order to rank the portfolios in last step and finally we achieve the best eco-design portfolio. The detailed elements of this decision tool will be described in next section.

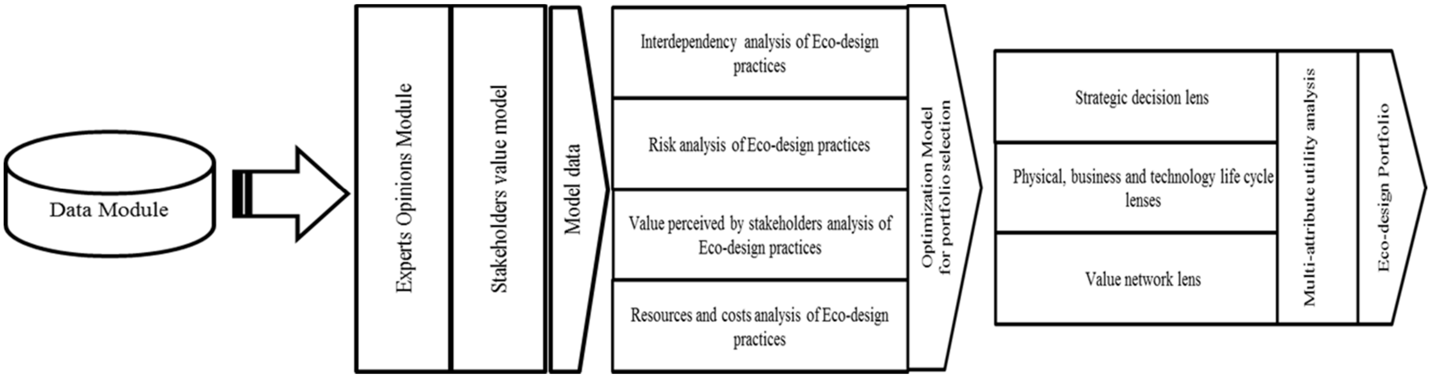


Figure 48 : The framework of decision model

For each Eco design practice we need to address the technical, environmental, economic and social features. Moreover we need the stakeholders need and expectations. The source of this data can be the models or in some cases expert opinions. The source of data for these four groups is shown in Table 15.

Table 15 : The source of data

Data	Source
Technical features	Design models /Experts opinions
Environmental features	LCA results /Experts opinions
Economic features	Economic models /Experts opinions
Social features	Experts opinions
Stakeholders need	Annual survey, Interviews with stakeholders and Experts opinions

4.2.5.2. Expert opinion Module

As we mentioned above, we need to link the fundamental models and technical calculations on a simplified basis to insert to decision tool while still keeping the detail knowledge as taken by the complex models.

The fuzzy number concept gives us this opportunity to translate this information to a certain range with considering the uncertainty of them. Fuzzy logic is the theory of fuzzy sets. These sets unlike Boolean logic which has two values are multi-valued and show the degrees of membership and degrees of truth. Hence they can express the vagueness of a variable. In other word, an element belongs to a fuzzy set with a certain degree of membership (Ganesh, 2008). With application of fuzzy numbers, the expert relates a fuzzy number to related feature for each practice. Fuzzy logic also supports the linguistic variables and therefore can be applied in the context of fuzzy subjective judgment of the evaluators. A linguistic variable is a variable with lingual expression. The evaluators are asked to perform their judgments. Each linguistic variable can be specified by a membership function.

4.2.5.3. Stakeholders value model

As we explained in section 4.2.2.3, an integrated approach for customer's value model is needed to cover the exchange, build-up and the dynamic aspects of value. In order to reflect the value exchange concept in the model, we need to address the associated risk, benefits and cost of implementing each Eco design practice for stakeholders. For considering the value build-up model , we need to address four aspects including the relationship between stakeholders and manufacturer, the types of perceived value (from tangible to intangible), the types of stakeholders need (utility need from psychics need) and finally view of stakeholders. With respect to dynamic aspect, we need to address level of satisfaction of stakeholders as the absence or presence of an attribute. Agouridas et al. (2006) proposed a methodology to support the initial analysis of stakeholder needs and attributes, and the derivation of corresponding design requirements. They applied the introduced method for a power solution case study. They used Maslow's hierarchy of needs concept (Handy, 1993) to address the level of stakeholders needs and relevant stakeholder's requirements which can be demonstrated by prospective solutions (hereafter attributes). This model supports two aspects of value build up models including (the types of stakeholders need and the type of perceived value).With applying the concept of fuzzy logic, we are also being able to address the level of satisfaction of customers as the result of absence or presence of attributes. The relationship between the needs of stakeholders and attributes can be obtained by applying this model. But we need to address the relationship of these attributes and Eco design features. For achieving this objective, we applied the concept of conjoint analysis and Lens model (Urban and Hauser, 1998). Lens model illustrates key concept of customer response to a new product and its marketing mix. Conjoint analysis also link features to perception and preference (for more details please see Urban and Hauser, 1998). The concepts of Lens model and resulted conjoint analysis have been illustrated in Figure 49, 50. The parameters of the proposed model and the formulation have been described in next part.

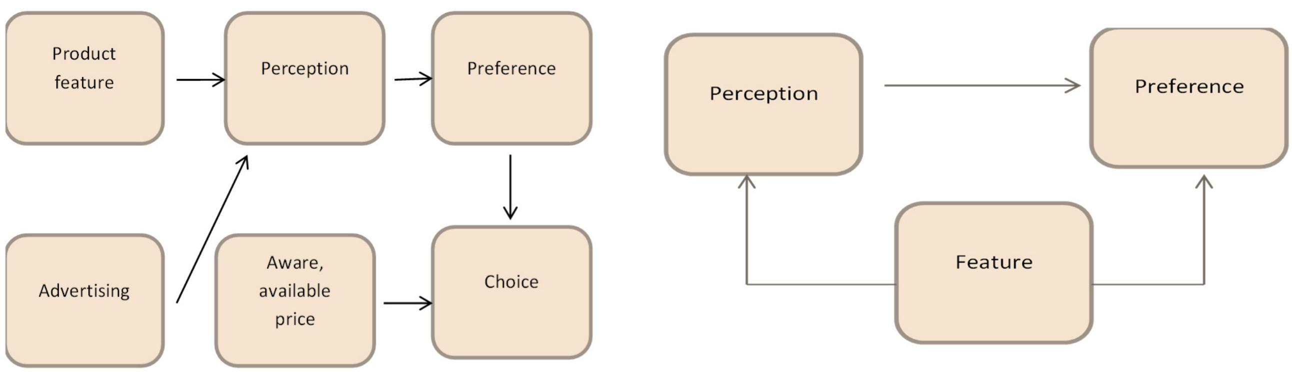


Figure 49 : Lens Model (Left) and conjoint analysis (Right), (Urban and Hauser, 1998)

Parameters

SN	Stakeholders Needs
SA	Stakeholders Attributes
$\widetilde{\omega i}$	The importance of need for stakeholders
$\widetilde{s i}$	The level of satisfaction of stakeholders need
$\widetilde{\gamma i}$	The weight of stakeholders attribute
$\widetilde{I i}$	The influence of stakeholders attribute
$\widetilde{C i j}$	The contribution of SAj in satisfaction of SNi
F	The Eco design features
$\widetilde{P i}$	The relevance preference of Eco design features with respect to stakeholders attributes

$\widetilde{R\iota J}$ The contribution of Fi in SAj

$\tilde{V}$ The perceived value for stakeholder as the result of implementing an Eco design practice

L1-L5 The level of stakeholders needs and attributes , (The stakeholders need and benefit of stakeholders in build-up model)

Model formulations:

$$\tilde{V} = \sum \widetilde{P\iota} \sum \widetilde{S\iota}\, \widetilde{\omega\iota} \tag{4.2.1}$$

$$where: \quad \widetilde{P\iota} = \sum \widetilde{R\iota J}\, \widetilde{\gamma\iota}\, \widetilde{I\iota} \tag{4.2.2}$$

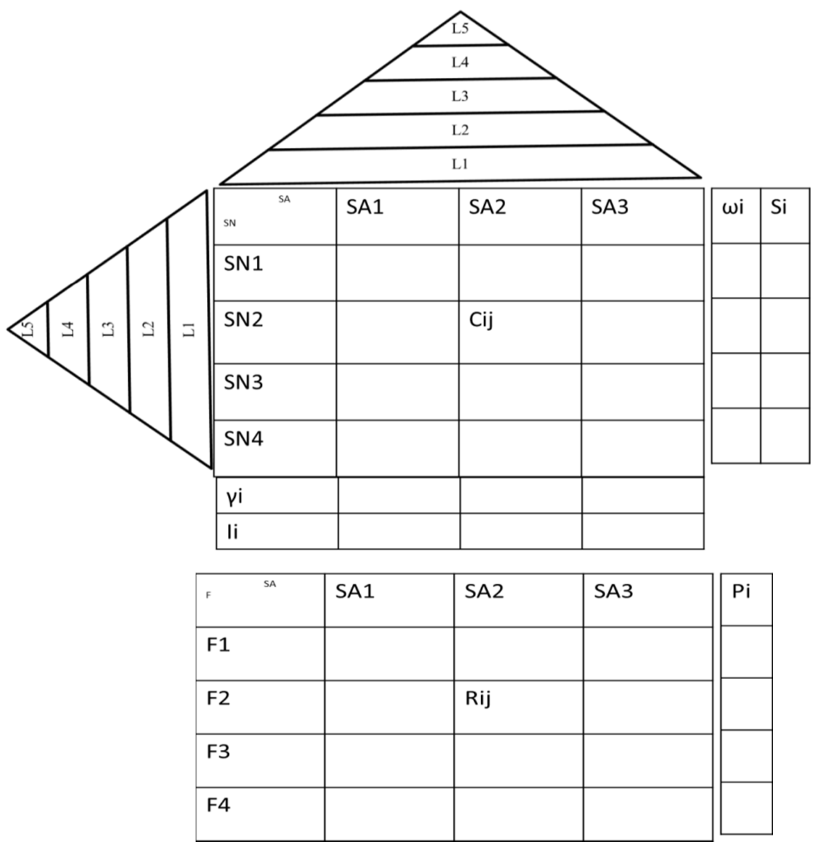


Figure 50 : Matrixes for finding perceived value by stakeholders as the result of implementation Eco-design Techniques

The detailed illustration of the model and an application example will be left for future studies because they depend on case under study. As we described above, the level of stakeholders needs and the types of benefits have been considered in this model to cover the concept of value build up. The stakeholders need can be varied from utility needs such as economic value to a physic needs such as power or authority. The benefits of prospective solutions also will be varied from tangible benefits such as a functional aspect to intangible such as innovation. The relevance indicators and weight and definition of attributes should also be defined by experts and based on the cases.

4.2.5.4. Portfolio selection

The Eco design portfolio selection problem is to select a set of practices from a pool of candidate techniques to maximize the expected value for all stakeholders. Each practice has specific characteristics such as relevant costs, associated risks, etc. Since the selection of Eco design practices may depend on the goals of the individual manufacturers and imprecision and flexibility are faced in making portfolio decisions, a fuzzy quadratic integer programming model is proposed here to optimize portfolio decisions in an uncertain environment.

Parameters and decision variables

N Number of eco-design techniques,

n Number of stakeholders

$\widetilde{v_{ikl}}$ The value perceived by stakeholder k as the result of implementing eco-design technique i alone in life cycle l

$\widetilde{S_{kl}}$ The salience of stakeholder k in life cycle l

$\widetilde{vs_{ijl}}$ The synergistic benefit of implementing technique i and j together

$\widetilde{C_{il}}$ The required cost for implementing technique i in life cycle l

$\widetilde{R_{eil}}$ The risk of environmental impact of implementing technique i in life cycle l

$\widetilde{R_{til}}$ The risk of technology associated to implementing technique i in life cycle l

$\widetilde{R_{mib}}$ The risk of market associated to implementing technique i business cycle b

$\widetilde{R_{ijb}}$ The shared risk by implementing technique i and j in business cycle b

$\widetilde{R_{ijl}}$ The shared risk by implementing technique i and j in life cycle l

Cs_{ijl} The shared cost by implementing technique i and j in life cycle l

$\breve{B}_l$ The maximum budget that can be spent in life cycle l

x_{il} $\begin{cases} 1 & If\ technique\ i\ is\ selected\ in\ life\ cycle\ l \\ 0 & othewise \end{cases}$

M $\{The\ set\ of\ required\ techniques\ for\ implementation$

R_{ijl} $\begin{cases} 1 & If\ technique\ i\ is\ required\ for\ implementing\ technique\ j \text{ in life cycle l} \\ 0 & othwise \end{cases}$

Mathematical formulation

$$\text{Max} \sum_{i=1}^{N}\sum_{l=1}^{4}\sum_{k=1}^{n}((\widetilde{(v_{ilk}} \times \widetilde{S_{kl}}) - \widetilde{C_{il}})x_{il} + \sum_{i=i}^{N-1}\sum_{j=i+1}^{N}\sum_{l=1}^{4}\sum_{k=1}^{n}((\widetilde{(vs_{ijk}} \times \widetilde{S_{kl})} - \widetilde{Cs_{ijl}})\, x_{il}x_{jl} \tag{4.2.3}$$

$$\text{Min} \sum_{i=1}^{N} \sum_{l,b=1}^{4} (\widetilde{R_{e\imath l}} + \widetilde{R_{t\imath l}} + \widetilde{R_{m\imath b}}) + \sum_{i=i}^{N-1} \sum_{j=i+1}^{N} \sum_{l,b=1}^{4} (\widetilde{R_{\imath\jmath b}} + \widetilde{R_{\imath\jmath l}}) x_{il} x_{jl} \quad (4.2.4)$$

$$S.t:$$

$$\sum_{i=1}^{N} \widetilde{C_{\imath l}} \leq \breve{B}_l \ \forall i \quad (4.2.5\ )$$

$$\sum_{l=1}^{4} x_{il} = 1 \ \forall i \in M \quad (4.2.6)$$

$$\sum_{l=1}^{4} x_{il} \leq 1 \ \forall i \quad (4.2.7)$$

$$x_{il} - x_{jl} \geq 0 \ \forall i, j, l \text{ such that } R_{ijl} = 1 \quad (4.2.8)$$

The objective (4.2.3) of this model is to maximize the total benefits of the portfolio. The benefit of each Eco design technique is the future value of implementing this technique for all stakeholders minus the total cost in the specific life cycle. We also considered the salience of each stakeholder as the coefficient for perceived value. As we described in section 4.2.2.2, the salience of stakeholder reflect the importance of stakeholders in network of stakeholders. As their importance can be changed during the life cycle of product, we defined this coefficient in relevant life cycle. The second term is an additional benefit derived from implementing technique i and j together. Objective (4.2.4) minimizes the associated risk of implementing the techniques. We considered three types of risks including environmental impact risk, technology risk and market risk. In these two objective functions, the shared costs as the result of implementation of technique i and j together and the shared risks have been considered. Constrain (4.2.5) ensures that the spending during the life cycle should not exceed the predetermined budget for each life cycle. Constraints (4.2.6) force to select certain techniques. Constraints (4.2.7) guarantees that that each technique t will not be implemented more than one. And finally Constraints (4.2.8) forces that the technique i can only be selected if all its required techniques are selected. We use an algorithm to find Pareto optimal solutions of this model. Usually meta-heuristic approaches are used to find the solution space. Genetic algorithm, particle swarm optimization and Pareto Ant Colony Optimization are some of these approaches (see references in Table 13). The details of solving procedure have been left for future study.

4.2.5.5. Value network lens

The portfolio selection model provides the optimal solutions based on the independent eco design practices characteristics and the interaction among techniques with respect to costs and values. But the synergistic aspects need to be assessed wisely. It is essential to link portfolio selection decisions to the key elements of manufacturer's strategies to maintain the balance of eco-design practices portfolio. Hence we added a layer to our proposed decision tool in order to evaluate such aspects. We called this layer as a decision lens in order to obtain the final solution considering the managerial insights to the problem. The first part of this layer is value network lens. Implementing the different Eco design techniques can change the relationships between stakeholders. As we described 4.2.2.3, according to the strategic social network formation, the structure of network can change the value function and the payoff of each player. For example applying some of Eco design techniques in category of material changes may need to some additional relationship with research centers or new suppliers. Moreover, in some cases the relationship type with some stakeholders can be changed via implementing an eco-design technique. Therefore, assessing the extracted network value as the result of these changes in stakeholder's network is important.

Method for calculating the overall value generated by a particular network as well as how it is allocated across the players can be obtained through allocation rule and value function (Demange and Wooders, 2006). There are different models for finding allocation rules; for example The Myerson allocation rule (Myerson,1997) and (Jackson & Wolinsky ,1996) allocation rule (linked based and player based) however for simplification in this study, we used the connection model (Jackson & Wolinsky ,1996) to address the value function in stakeholders network. Application of other value functions can propose for future studies. In connection model the pay-off player i receive from network g is defined based equation and the value function will be as the equations 4.2.9, 4.2.10:

$$Y_i = \sum_{j \neq i} \delta_{ij}^{d(i,j)} - \sum_{j:ij \in g} c_{ij} \tag{4.2.9}$$

Where

δ_{ij} and c_{ij} is the benefit of direct connection between i, j and its cost respectively and $d(i,j)$ is the number of links in shortes path

$$v(g) = \sum_i Y_i(g) \tag{4.2.10}$$

For each optimal portfolio, we consider the structure of stakeholder's network and we can calculate the allocation rule for interested stakeholders of total value as the result of network game. Appendix A shows the details.

4.2.5.6. Life cycles and Strategic decision lens

To successfully utilize resources, it is important for manufacturers to link design for environment objectives to the key business strategies. According to (Khurana and Rosenthal, 1998) the greatest success comes to enterprises that take a holistic approach to effectively linking business strategy, product strategy, and product-specific decisions.

Fiksel, (1996) demonstrates the different interpretation of business and physical life cycles. He also described the different aspects of these life cycles including time scale, responsibility and continuity. These aspects and dual life cycle have been shown in Figure 51. According to the author, business life cycle provides a framework for decisions regarding product features and costs or trade-offs efforts. While the physical life cycle focus on environmental issues, performance evaluation and standards. The Eco design decisions need to be made under a framework which considers the different aspects of business and physical life cycle. Moreover the design cycle and technology cycles are two other aspects which should be considered in selection process of Eco design practices. According to (Rose, 2001) the design cycle is the frequency with which companies design new products or redesign their existing products. It relates to competition's release of new products, marketing plans and concrete research and development accomplishments. The technology life cycle also reveals the length of time before mechanisms supporting the main functions of the product become non-operational (Rose, 2001). This feature of product may be affected as the result of implementation of eco design practices. There are different eco design practices which can be implemented in different value added operations by manufacturers. (Van Hemel and Brezet, 1997) introduced 33 Eco design principles which are a priori clustered into eight Eco design strategies on the basis of literature analysis and Eco design experiences. We briefly demonstrated some of these practices applicable in different manufacturers operations (Figure 52). Now with respect to the diversity of eco design practices from different aspects, decision makers need to assess the optimal portfolios with respect to these types of diversities. Hence decision makers with respect to long term strategies of organization can choose the better portfolio at the final step.

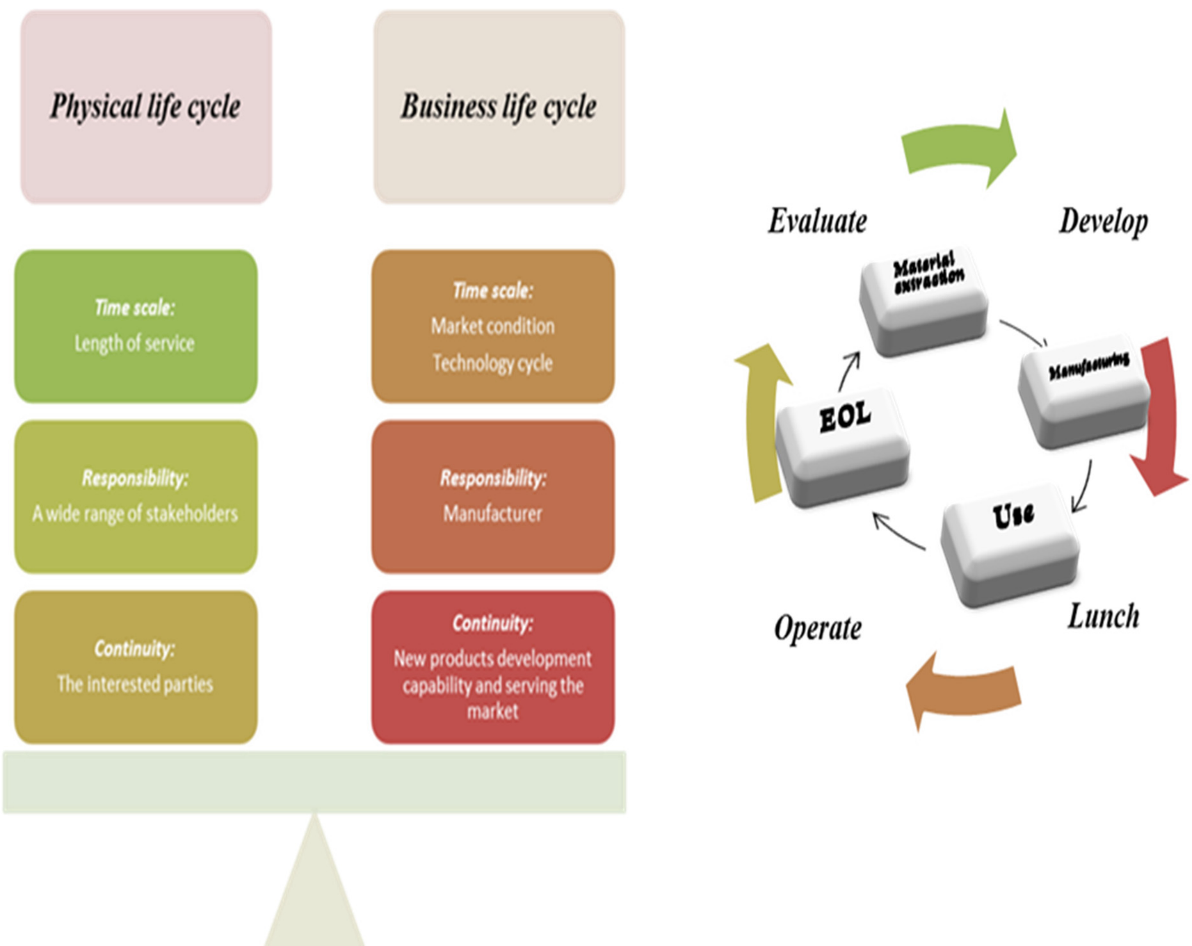


Figure 51 : Physical and Business Life cycle (adapted from Fiksel, 1996)

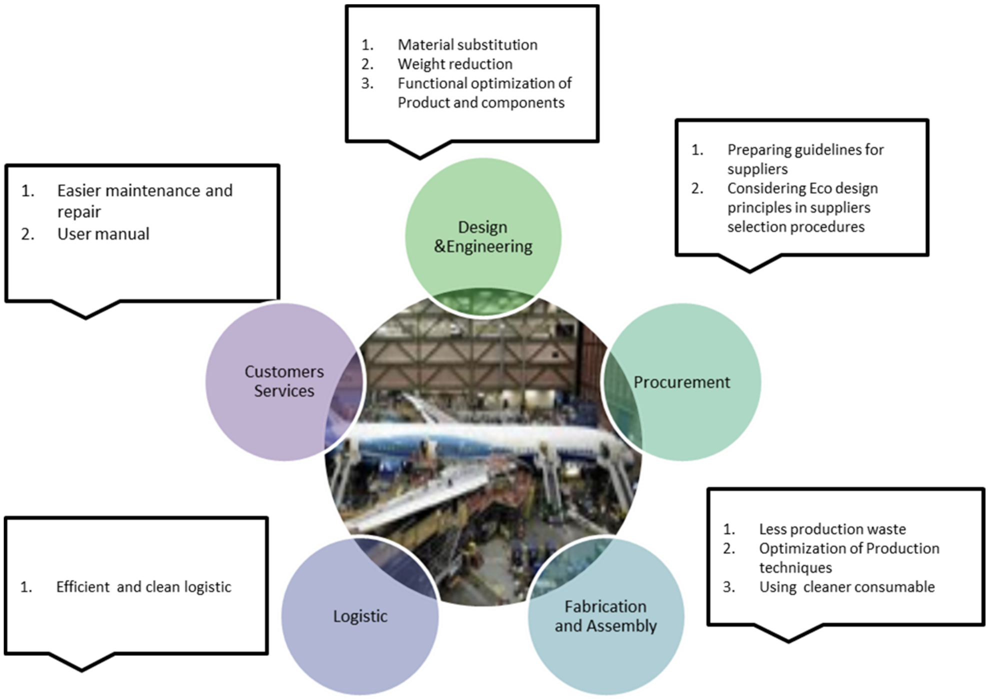


Figure 52 : Eco design Practices in different manufacturers value added operations

4.2.5.7. Multi attribute utility analysis

The last part of the decision tool is a multi-attribute utility tool in order to compare the alternative portfolios by aggregating the measures of portfolio attributes. We used 10 attributes for comparing the alternatives. However these attributes can be changed based on the needs of case under study. We used the value and risk score of alternative portfolio from portfolio optimization model. The life cycle and strategic characteristics which have been explained in previous part are next attributes. We assumed that the network values for two preferred stakeholders are important for manufacturers (it can be changed based on the need of manufacturers) and finally the value of network. The description of the model has been provided in Appendix A and equations 4.2.11, 4.2.12.

4.2.6. Application

In this part we proposed a guideline for application of developed decision tool in selection of Design for end of life practices for aircraft manufacturers. The real application with results is subject to apply the proposed model in elected aircraft manufacturer as a pilot. Obviously, the parameters and application procedure can be adopted based on the requirement of the case study. The action research to justify and to evaluate the level of decision tool applicability and effectiveness will be the research agenda of authors.

4.2.6.1. Aircraft manufacturers and corporate social responsibility

Recently, considerably extensive attention to sustainable development, including the social impacts of aviation, has started becoming a key aspect in aviation industry. Aircraft manufacturers have reacted to this situation and recognized the importance of focusing their efforts to integrate sustainable development policies into their core business strategies. However, the effectiveness and the efficiency of such efforts have been in question because systematic approaches to support such activities are limited (Morimoto and Agouridas, 2009). The authors believe that at present, stakeholder analysis, and engagement are widely accepted in the aviation sector. However such stakeholder analysis should be performed in a more structured and integrated manner to provide better support to aircraft manufacturers to apply sustainable development strategies effectively. They conclude that there is a crucial necessity for the aviation industry to operationalize system development methods which consider life cycle and stakeholder considerations.

Except legal necessities REACH (Registration, Evaluation, Authorisation and Restriction of Chemical Substances (EU)) and RoHS (Restriction of Hazardous Substances (UK Directive)), there are no further regulations and directives which force aviation industry to become more environmental friendly. Hence the key driver of producer behavior is generated by the market itself. The new and greener design is important to protect the environment for aircraft operations. Considering long service life, new aviation design takes more than a decade to develop. This indicates the requirements for eco-design practices including green design and production, withdrawal, and recycling of aircrafts and their components originating from repair actions. With these practices, aircraft manufactures be able to minimize the use of raw materials and energies as a result improving the environmental and the social impact of the whole products life cycle. But, the field of eco-design for aircraft and its effects for the whole lifecycle as well for society have not been studied systematically (Morimoto and Agouridas, 2009).

To meet the REACH goals as well as RoHS requirements, the European Union and the aviation industry initiated the € 1.4 billion R&D project CleanSky (Bollhöfer et al., 2012). This project has 6 integrated technology demonstrations which Eco-design is one of them.

Bollhöfer et al., (2012) utilized results from the CleanSky work focusing on eco-design guideline as well as a literature review and expert interviews on societal belongings within the aircraft industry and its stakeholders to study Eco Design requirements, processes and methods for implementation. In order to develop a model to support technical decision processes they compared three approaches including multi-criteria decision, Social life cycle assessment (SLCA) and European Foundation for Quality Management (EFQM).The result of this study shown in Figure 53.

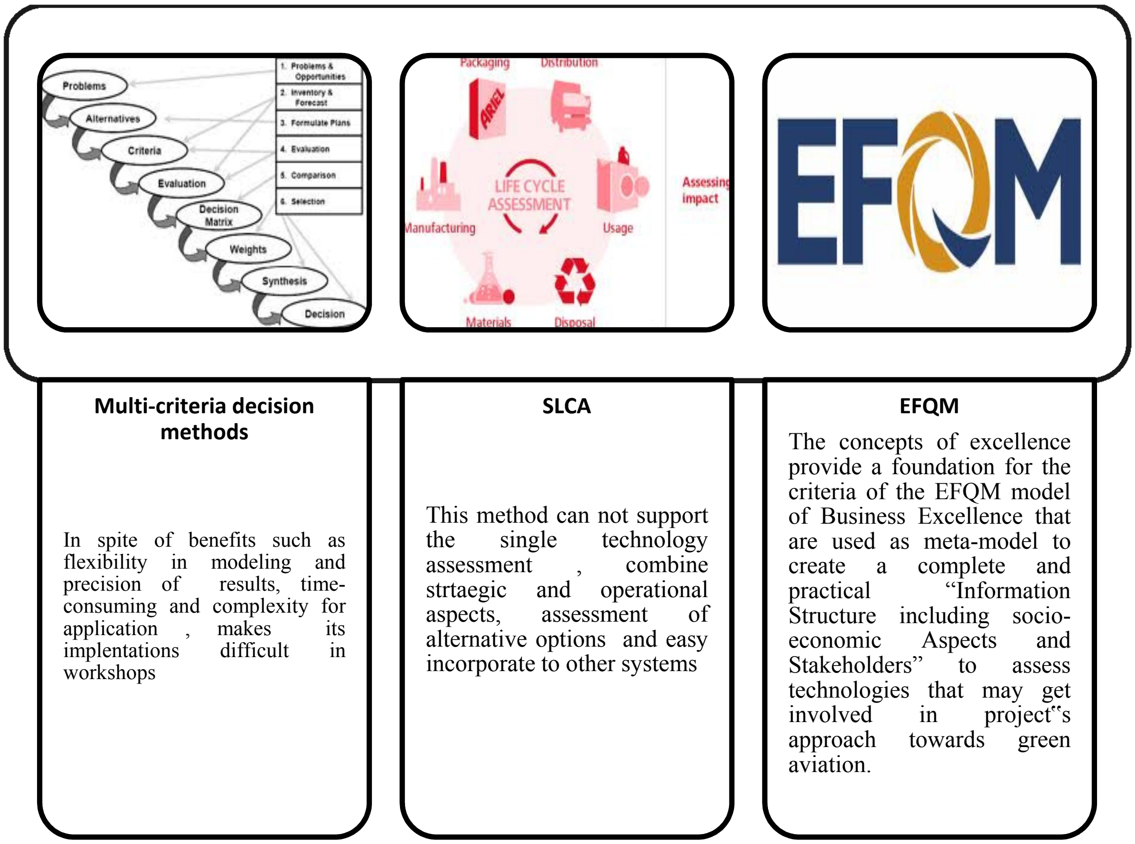


Figure 53 : Three approaches

Bollhöfer et al., (2012) suggested EFQM as a framework for developing guiding questions for green aviation which cover the leadership aspect, strategic contribution, process requirements, people, customer and society results. However it cannot provide a precise assessment for comparing the different alternatives considering multi aspects nature of implementation of Eco design practices. In the next part we focus on a new aviation problem with respect to the retired aircrafts. As recently the design for recycling and generally the eco-design practices which make benefits for limiting the environmental impact of aircraft at the end of life, is one area in green design terminology which has been taken into account, we study the application of our proposed decision tool in this context.

4.2.6.2. Problem context (Aircraft at the End of life)

Over the years the aircraft depreciate in value. The cost of maintenance and repair will be increased. Customer satisfaction and reduced fuel consumption are the other aspects of the decision that aircraft operation is no more acceptable. When the owner comes to this decision it faced by several options. After storage time, if the aircraft is worth more than its parts it can be sold as a flyer. If this option is not valuable the aircraft has to be dismantled, reused or disposed (Heerden & Curran, 2010).

In the global market forecast of Airbus for the period 2009–2028, 8453 aircraft are projected to be retired (Heerden & Curran, 2010). Based on Boeing's report, the potential market for aircraft disposal will be nearly 6000 by 2028. (Green sky, aviation and the environment, 2010) A substantial and novel industry problem has occurred as a result of large numbers of useless aircraft and the related environmental issues (Heerden & Curran, 2010).

Numerous important components can be retained before dismantling, recycling or disposal. Engines, landing gears, avionics, and electronic motors are the most common parts which may be reused. Doors, wings, interiors can be used for training purpose (The Aircraft at End of Life Sector).

Four major classes of materials ranging from low cost interior materials to high performance alloys and composites used in aircraft construction. For old models, the aluminum is main material with a high achievement in recycling technologies but in new models with using composites, the recycling is challengeable.

Aircraft original manufacturers have a long history of looking for ways to reuse or recycle aircraft and their components. In the past, at least 50 percent of the material used in aircraft construction was reused or recovered. (Watson, 2009) Different companies worked on this problem during recent decade. Based on the core business of these companies, they follow different strategies, practices and process for implementing the end of life solutions (Siles, 2011).

The two largest airframe manufacturers, Airbus and Boeing, are at the head of research and main projects in this field. Airbus PAMELA project has successfully confirmed that as much as 85 percent of an aircraft by weight can be recovered for recycling (Watson, 2009).

Boeing has taken a leadership role in aircraft life cycle and end-of-service recycling strategies for more than 50 years. Aircraft Fleet Recycling Association (AFRA) is a global consortium of more than 40 companies that provides environmentally responsible options for aging aircraft. This includes maintaining and reselling reliable airplanes and returning them to service. Safe parts recovery, scrapping and recycling services are available for airplanes that cannot be returned to service (Boeings environmental report, 2010).

North & Macal, (2007) believe that markets, particularly those far from the standard forms analyzed in economic theory (for example, perfect competition, monopoly, and oligopoly) and social systems, especially those within industrial and government organizations, are examples of system, which have been complex. Hence, second hand part market of aircraft components, the role of local or global authorities and the lobbying interface among different stakeholders are the other factors, which intensify the complexity in these projects.

4.2.6.3. Guideline

This part is intended to provide a step by step process for applying the introduced decision tool in this study for comparing different Eco design practices applicable for EOL aircraft. Throughout this guideline, some examples and templates are provided for conducting the methodology where needed.

4.2.6.3.1. Step 1: Identifying aircraft manufacturers green strategy

The first task in this process is to define and clarify the strategic objectives of manufacturer in Eco design department or division. Aircraft manufacturer need to link design for environment objectives to the key business strategies. Usually the green strategy should be defined with effectively linking business strategy, product strategy, and product-specific decisions. The budget constrain, the acceptable level of risk and uncertainty, the propriety of practices, the important stakeholders are some of important parameters which can be defined according to green strategy.

4.2.6.3.2. Step 2: Identifying the Eco design practices and relevant features and characteristics

There are different types of eco design practices which can be implemented by aircraft manufacturers which decrease the adverse EOL impacts. Based on literature review and industrial expert's discussion, we classified these eco practices in three groups including material usage, providing information and manuals and design for 3R (Re-using, Reducing and Recycling). Figure 54 shows the different practices. However aircraft manufacture can choose the ultimate alternatives based on the priorities which have been recognized in Step 1.

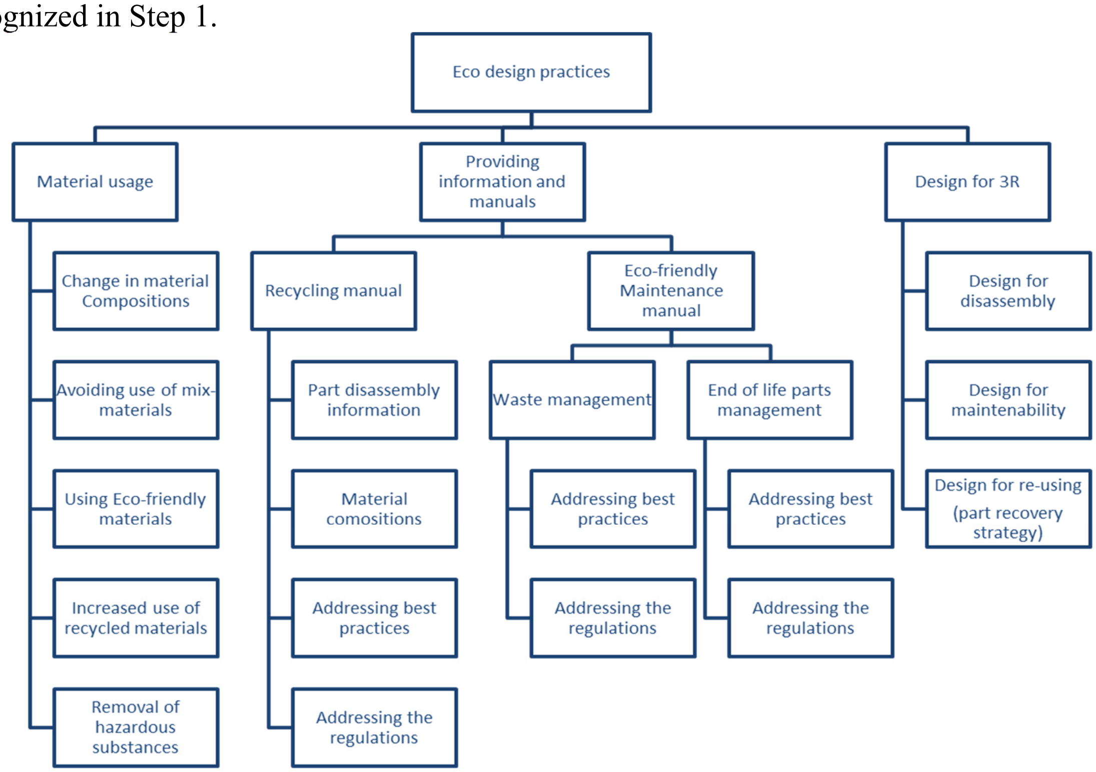


Figure 54 : Eco practices with impacts on EOL

For each Eco design practice we need to address the technical, environmental, economic and social features. As we explained before the sources of data are design models, LCA software, Economic models and experts opinions. Table 16 shows an example of applying expert module for technique A. the experts make their evaluation with respect to each feature as a triangular fuzzy number within the scale range of 0–10.

Table 16 : An example of Technique A and different aspects

	The Different aspects	The effect of applying Technique A		
		Low	Medium	High
Environmental Aspects	Fossil consumption			
	Nonfossil consumption			
	Process (electrical and nonelectrical)			
	Feedstock			
	Transportation			
	Material consumption			
	Carbon dioxide emission			
	Carbon monoxide emission			
	Nitrous oxides (NOx) emission			
	Sulfur oxides (SOx) emission			
	Nonmethane hydrocarbons (NMHCs) emission			
	Solid waste generation			
	Noise			
Economic Aspects	Price of virgin materials			
	Supply chain adaptability(time +supplier+cost+quality)			
	Fuel saving			
	Fleet value			
	Scrap price- Economic value of recycling			
	Price of virgin materials			
	The effect on image			
	Feasibility			
Social Aspects	Employment			
	Product risk			
	Health risk			
	Local development			

Now we need to address the other characteristics of the eco design practices. The diversity among the eco design practices in term of life cycle which will be affected, the effect on technology cycle, design cycle and category of strategy which have been explained in details in section 4.2.3.6. In order to provide better explanation, one example has been illustrated in this part. Suppose that we have 13 different techniques. For each technique, the characteristics are provided in Table 17 (These characteristics have been obtained from expert's opinions). In order to show the diversity among techniques, we used clustering approach by self-organizing map that combined multi-criteria, spatial and visualization capabilities. With this technique we can visualize d-dimensional space in two dimensions (for more details see Vesanto et al. 2000). The Figure 55 shows the clusters of techniques. The last sub figures (Labels) shows the diversity among these techniques. The associated costs and risks of each technique also should be determined by experts in order to insert to the portfolio optimization model.

Table 17 : The different characteristics of eco design techniques

Techniques	Physical Life cycle for implementation	Business life cycle can be affected	The effect on Technology life cycle	The effect on design cycle	Category of strategy
1	1	3	1	2	8
2	1	1	3	4	6
3	4	2	1	1	3
4	3	1	1	3	6
5	1	1	1	4	2
6	1	4	2	3	1
7	2	1	1	5	1
8	1	2	2	2	3
9	3	2	3	1	7
10	4	3	1	4	4
11	1	2	2	1	2
12	2	4	3	2	3
13	1	2	1	5	1

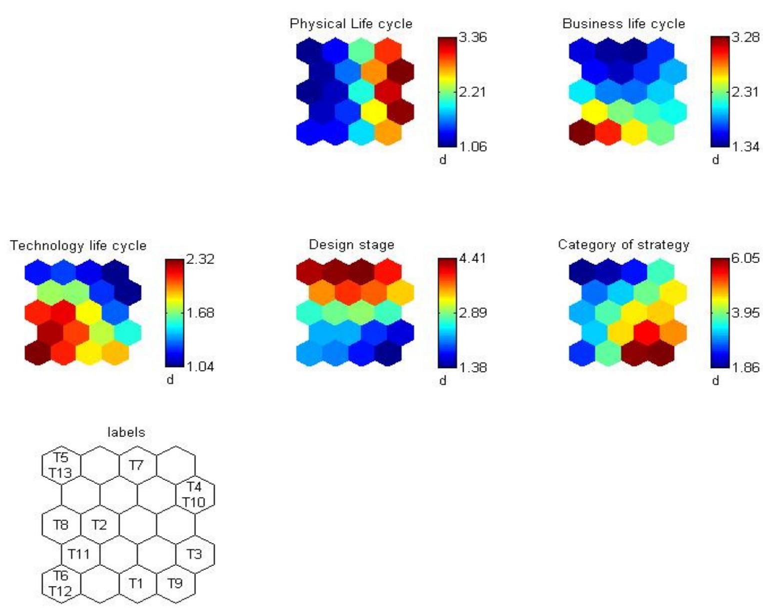


Figure 55 : The clusters of 13 eco design techniques

4.2.6.3.3. Step 3 : Mapping Stakeholders Network

Mapping stakeholder's network includes identifying the stakeholders, visualizing stakeholder map and determining the change in network structure caused by different types of Eco design characteristics.

4.2.6.3.3.1. Identifying stakeholders and their relationship

Identifying the stakeholders is one of the most important parts of the decision tool. Aircraft manufacturers need to know their stakeholders because value creation cannot be achieved without understanding and anticipating their needs and expectations. Figure 56 shows the key players of aircraft EOL problem and preliminary value map of their relationship network. For some stakeholders, the values and needs data were quite rich or easy to find; others were more challenging. The template for identifying stakeholders and their characteristics has been shown in Table 18.

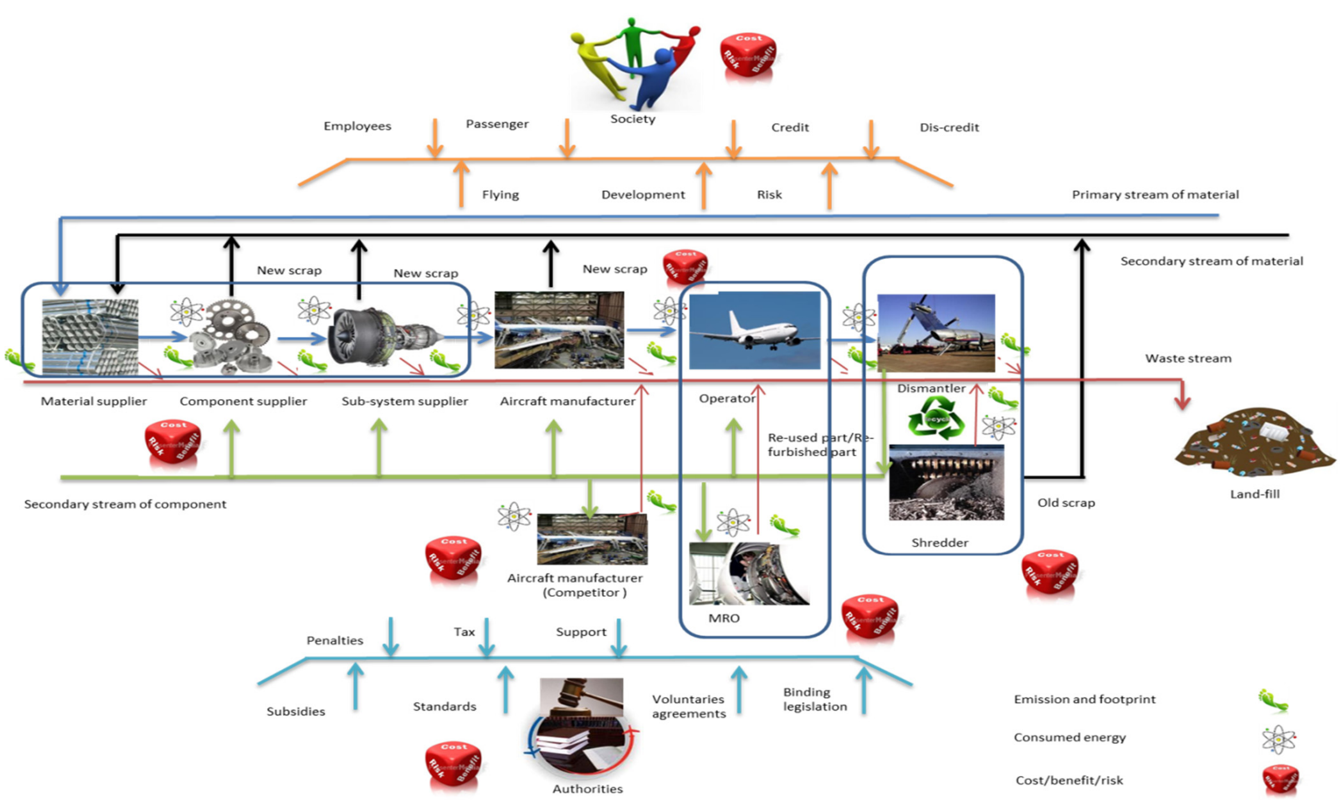


Figure 56 : Stakeholders for EOL aircraft problem and preliminary value map

Table 18 : Template for stakeholders required Data

Stakeholders	Role	Specific Needs	Relationship			Salience		
			Current level	Orientation level	Trust level	Critically	Power	Legitimacy
Employees								
Product Development								
Research								
Service Administration								
Customers								
Leasing companies								
Airlines								
Shareholder and investors								
Suppliers								
Tier 1								
Tier 2								
Tier 3								
Communities								
Local communities								
Environmental communities								
Aerospace communities								
Media								
Academia Universities								
Research centers								
Industry partnership and association								
Aerospace associations								
Environmental associations **Non-Government Organizations**								
National NGO								
International NGO								
Government and regulatory authorities								
Aerospace authorities International Authorities								
Local Government								
Recyclers								
Dismantlers								
Shredder s **Competitors**								

4.2.6.3.3.2. Network structure as the result of eco design technique implementation

As we describe in section 4.2.3.5 implementing the different Eco design techniques can change the relationships between stakeholders. Hence it's needed to demonstrate the different network structures in each eco design technique. For example suppose we have three techniques and four stakeholders. The effect of applying each technique on stakeholder's network is shown in Figure 57.

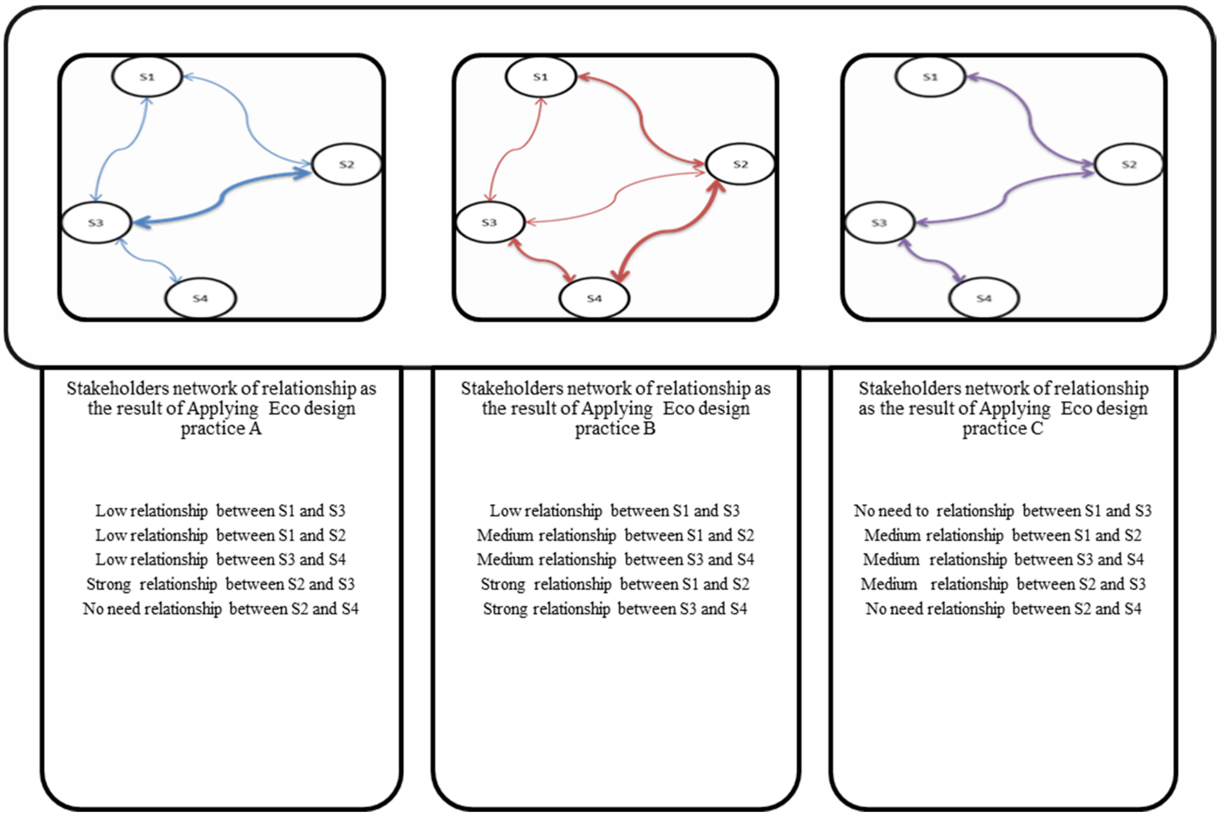


Figure 57 : The effect of applying Eco design techniques on stakeholder's network

4.2.6.3.4. Step 4: linking the Eco design features and stakeholders need

After identifying the eco design features and stakeholder's need, the experts need to extract the stakeholder's attributes in order to be used in stakeholder value model. These attributes can be defined based on stakeholder's requirements which can be demonstrated by prospective solutions. The judgment with respect to the parameters of the stakeholder's value model should be done by experts and the framework described in section 3.3 can be completed.

4.2.6.3.5. Step 5: Applying the decision tool

Now the data are available in order to insert to decision tool. In first layer of this decision tool, the Pareto optimal portfolios can be obtained. In the second layer multi-attribute utility theory will be applied according to expert's opinions in order to comparing optimal portfolio alternatives and finally the final result and the selected portfolio will be achieved.

4.2.6.3.6. Step 6: Evaluation

The final result of decision tool needs to be assessed and evaluated. Based on decision maker's expectation, they decide to either accept or reject the portfolio. If the portfolio is adequate and aligned with strategic objectives, it can be saved as a potential eco design portfolio. Otherwise, the process should be repeated. In this case, changing some parameters in objectives or constrains or modification in data may be needed in order to meet the satisfactory scenario.

4.2.7. Conclusion and future research

Todays with inclusive attention to corporate social responsibility, manufacturers require aligning their green strategies with stakeholder's needs and expectations. In this study we developed a decision tool to aid manufactures in early stage of design for their green strategy choices. This model provides manufacturers by an evaluation tool to select a portfolio of eco design practices to maximize the value perceived by all stakeholders in a dual life cycle approach including the business product life cycle as well as physical life cycle. A portfolio selection approach has been used to maximize the network value of stakeholders considering the life cycle cost and risk of techniques while satisfying the diversity of allocation resources on eco design practices based on strategic objectives of manufacturers. We also introduced a step by step guideline in order to utilize the introduced methodology for selecting a portfolio of design for EOL practices for aircraft manufacturers. The pilot application of the proposed decision tool for an aircraft manufacture will be the research agenda for authors. This pilot application with interviews with industrial experts makes this opportunity to evaluate and improve the proposed model.

References

Agouridas, V. (2006), "Early alignment of design requirements with stakeholder needs ",Proc. IMechE Vol. 220 Part B: J. Engineering Manufacture

Agouridas, V. and Morimoto,R.(2009)," Supporting Aircraft Manufacturers to Formulate and Implement Sustainable Development Strategies Systematically" Journal of the Transportation Research Board, No. 2106, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 12–19.

Allee V. (2008),"Value network analysis and value conversion of tangible and intangible assets", Journal of Intellectual Capital, Vol. 9 Iss: 1 pp. 5 – 24

Azaddin Salem Khalifa, "Customer value: a review of recent literature and an integrative configuration", Emerald 42, (2004)

Badri, M. et al., (2001)," A comprehensive 0–1 goal programming model for project selection. International Journal of Project Management, 19, 243–252.

Barsky, N.P., Hussein, M.E., Joblonsky, S.F. (1999) "Shareholder and stakeholder value in corporate downsizing: the case of United Technologies Corporation", Accounting, Auditing & Accountability Journal, Vol.12 No.5 pp583-604

Boeing 2010 Environment Report

Boks, C. (2000) "Assessment of Future End-of-Life Scenarios for Consumer Electronic Products." Design for Sustainability. Delft, NL, Delft University of Technology.

Bollhöfer, E. et al. (2012)," EcoDesign 2020:Green Design requirements and implementation in the aircraft-industry Germany) – September 14, 2012

Bovea, M.D. and Pérez-Belis, V. (2012)" A taxonomy of ecodesign tools for integrating environmental requirements into the product design process", Volume 20, Issue 1, Pages 61–71

Bussy, N. and Kelly, L. (2010)," Stakeholders, politics and power towards an understanding of stakeholder identification and salience in government" Journal of Communication Management Vol. 14 No. 4, pp. 289-305

Chien, Ch. (2002), "A portfolio evaluation framework for selecting R&D projects", R&D Management 32, 4,359-368

Davidsson, B. (1998), "Modified Product Quality Tools for Improved Environmental Design in Small and Medium Sized Enterprises", IIIEE Master's theses 98:9. International Institute for Industrial Environmental Economics, Lund University, Lund.

Demange, G. and Wooders, M.,(2006)," Group Formation in Economics:Networks, Clubs, and Coalitions", Cambridge university press

Dey, P. K. (2006), "Integrated project evaluation and selection using multipleattribute decision-making technique", International Journal of Economics, 103, 90–103.

Doerner, K et al. (2004)," Pareto ant colony optimization: A met heuristic approach to multi-objective portfolio

Driessen, Theo (1988), Cooperative Games, Solutions and Applications, Kluwer Academic Publishers

Emilie Danna et al. (2008), " Generating Multiple Solutions for Mixed Integer Programming Problems",ILOG CPLEX R&D

Fiksel, J. (1996) "Design for environment: creating eco-efficient products and processes", McGraw-Hill, USA.

Ganesh, (2008), " Introduction to Fuzzy sets and Fuzzy logic", Prentice- hall

Golabi, K. et al., (1981), "Selecting a portfolio of solar energy projects using multi-attributes preferwence theory. Management science, 27,174-189

Grossi, I. (2003) "Stakeholder Analysis in the Context of the Lean Enterprise", Master thesis, MIT

Hall, N.G. et al. (1992),"A model for making project funding decision at the National Cancer Institute", Operation Research, 40, 1040-1052

Halog A. et al. (2001), "Using quality function deployment for technique selection for optimum environmental performance improvement", Journal of Cleaner Production, 9 (2001), pp. 387–394

Handfield, R., et al. (2001) "Integrating Environmental Concerns into the Design Process: The Gap between Theory and Practice" IEEE Transactions on Engineering Management, VOL. 48, NO. 2

Handy, C. Understanding organizations, 4th edition, 1993 (Penguin Group, London, UK) pp. 180–190.

Heerden, D. and Curran.R. (2010). Value Extraction from End-of-Life Aircraft, Encyclopedia of Aerospace Engineering

Jackson M. Wolinsky, A., (1996)," A Strategic Model of Social and Economic Networks", journal of economic theory 71, 44_74

Jackson, M., (2008),"Social and Economic Networks ",Princeton University Press

Karlsson, R. and Luttropp, C. (2006)," EcoDesign: what's happening? An overview of the subject area of ecodesign and of the papers in this special issue" Journal of Cleaner Production, 14 (2006), pp. 1291–1298

Khurana, A., and Rosenthal, S. R. (1998),"Towards Holistic "Front Ends" in New Product Development. Journal of Product Innovation Management, Vol. 15, pp. 1557–1574.

Langtry, B. (1994) "Stakeholders and the moral responsibilities of business", Business Ethics Quarterly, Vol.4 No.4 pp431-43

Leszinski, R., Marn, M.V. (1997) "Setting value, not price", The McKinsey Quarterly, No.1 pp99-115

Medaglia, A. L. et al. (2007), " A multiobjective evolutionary approach for linearly constrained project selection under uncertainty", European Journal of Operational Research, 179, 869–894.

Mitchell R.K et al. (1997)," Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts, Academy of Management Review" Vol. 22, No. 4, pp. 853-886

Mukherjee, K., and Bera, A. (1995)," Application of goal programming in project selection decision – A case study from the indian coal mining industry",European Journal of Operational Research, 82, 18–25.

Myerson, R., (1997)," Graphs and Cooperation in GamesAuthor(s): Mathematics of Operations Research", Vol. 2, No. 3, pp. 225-229

Normann, R. (2001) Reframing Business: When the Map Changes the Landscape,

Normann, R., Ramírez, R. (1994) Designing Interactive Strategy: From Value Chain to Value Constellation,

North, M. & Macal, C. (2007). Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation, Oxford University Press: New York, NY

Peerenboom, J.P et al., (1989), "Selecting a portfolio of enviornmtela program for a synthetic fuel facility", Operations research, 37, 689-699

Polonsky M.J. et al. (2002), "A Stakeholder Perspective for Analyzing Marketing Relationships", Journal of Market-Focused Management, Volume 5, Number 2, June 2002 , pp. 109-126(18)

Rabbani, M. et al. (2006), "A comprehensive model for R&D project with 0–1 linear goal programming",International Journal of Engineering, 19, 55–66.

Rabbani, M. et al. (2010)," Multi-objective particle swarm optimization for project selection problem ",Expert Systems with Applications 37 (2010) 315–321

Roa, V.R et al., (1991), "a balanced model for evaluating firms for acusisition", Management science, 37- 331-349.

Rose, C. (2000) "Design for Environment: A Method for Formulating Product End-Of-Life Strategies" PhD thesis, Stanford University

Rowley T.J. (1997)," Moving Beyond Dyadic Ties: A Network Theory of Stakeholder Influences ", Academy of Management Review, Vol. 22, No. 4, pp. 887-910, Santhanam, R., and Kyparisis, J. (1995), “ A multiple criteria decision model for information system project selection” Computers and Operations Research, 22, 807–818.

Santhanam, R., and Kyparisis, J. (1996).,” A decision model for interdependent information system project selection” European Journal of Operational Research, 89, 380–399.

selection. Annals of Operations Research, 131, 79–99.

Siles, Ch. (2011). Aide à la décision pour la gestion d’un parc d’avions en fin de vie, École Polytechnique De Montréal

Sutherland, T. (2009),” Stakeholder value network analysis for space-Based Erath Observation” Master thesis, MIT.

The Aircraft at End of Life Sector: a Preliminary Study: http://users.ox.ac.uk/~pgrant/Airplane end of life.pdf, [accessed on March 12]

Urban, G.L. and Hauser, J.R, (1998),” Design and Marketing Of New Products “, Prentice-Hall, 1980

Van Hemel CG et al. (1997),” A promising approach to sustainable production and consumption. United Nations Environmental Programme, Paris; 1997.

Van Hemel, C. (1998) "Ecodesign empirically explored - Design for Environment in Dutch small and medium sized enterprises." Design for Sustainability. Delft, NL, Delft University of Technology: 271.

Vesanto,J. et al.(2000), “,SOM Toolbox for Matlab 5”, SOM toolbox team, Helsinki University of technology report A57

Watson, M. (2009). End of Aircraft Life Initiatives, SBAC Aviation and Environment Briefing Papers, Available at: http://www.sustainableaviation.co.uk/wp-content/uploads/end-of-aircraft-life-initiatives-briefing-paper-11.pdf. [accessed on March 12]

Wikstrom, S., Normann, R. (1994) Knowledge and Value: A New Perspective on Corporate Transformation

Appendix A

Com Portfolios	Portfolio optimization result		Life cycle lens			Strategic decision lens		Value network lens		
	Value score	*Risk score*	*Physical Life cycle diversity*	*Business life cycle Diversity*	*Technology life cycle Diversity*	*Design stage diversity*	*Category of strategy diversity*	*Networks value for Preferred stakeholder 1*	*Networks value for Preferred stakeholder 2*	*Total network value*
	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}
Portfolio A:$A_{1\ldots n}$	$\sum_{i\in N} v_{A_i}$	$\sum_{i\in N} R_{A_i}$	$-\sum_{i\in N}(l^{ph}_{A_i} - \bar{l}^{ph}_{A})^2$	$-\sum_{i\in N}(l^{b}_{A_i} - \bar{l}^{b}_{A})^2$	$-\sum_{i\in N}(l^{t}_{A_i} - \bar{l}^{t}_{A})^2$	$-\sum_{i\in N}(s_{Ai} - \overline{s_{Ai}})^2$	$-\sum_{i\in N}(st_{Ai} - \overline{st_{Ai}})^2$	Y_{AI}	Y_{A2}	$v_A(g)$
Portfolio B:$B_{1\ldots n}$	$\sum_{i\in N} v_{B_i}$	$\sum_{i\in N} R_{B_i}$	$-\sum_{i\in N}(l^{ph}_{B_i} - \bar{l}^{ph}_{B})^2$	$-\sum_{i\in N}(l^{b}_{B_i} - \bar{l}^{b}_{B})^2$	$-\sum_{i\in N}(l^{t}_{B_i} - \bar{l}^{t}_{B})$	$\sum_{-i\in N}(s_{Bi} - \overline{s_{Bi}})^2$	$-\sum_{i\in N}(st_{Bi} - \overline{st_{Bi}})^2$	Y_{B1}	Y_{B2}	$v_B(g)$
Portfolio C:$C_{1\ldots n}$	$\sum_{i\in N} v_{C_i}$	$\sum_{i\in N} R_{C_i}$	$-\sum_{i\in N}(l^{ph}_{C} - \bar{l}^{ph}_{C})^2$	$-\sum_{i\in N}(l^{b}_{C_i} - \bar{l}^{b}_{C})^2$	$-\sum_{i\in N}(l^{t}_{C_i} - \bar{l}^{t}_{C})$	$-\sum_{i\in N}(s_{Ci} - \overline{s_{Ci}})^2$	$-\sum_{i\in N}(st_{Ci} - \overline{st_{Ci}})^2$	Y_{CI}	Y_{C2}	$v_C(g)$

$$U_A = w_1\left(u\left(\sum_{i\in N} v_{A_i}\right)\right) + w_2\left(u\left(\sum_{i\in N} R_{A_i}\right)\right) + w_3\left(u\left(-\sum_{i\in N}(l^{ph}_{A_i} - \bar{l}^{ph}_{A})^2\right)\right) + w_4\left(u\left(-\sum_{i\in N}(l^{b}_{A_i} - \bar{l}^{b}_{A})^2\right)\right) + w_5\left(u\left(-\sum_{i\in N}(l^{t}_{A_i} - \bar{l}^{t}_{A})^2\right)\right) + w_6\left(u\left(-\sum_{i\in N}(s_{Ai} - \overline{s_{Ai}})^2\right)\right) + w_7\left(u\left(-\sum_{i\in N}(st_{Ai} - \overline{st_{Ai}})^2\right)\right) + w_8\big(u(Y_{AI})\big) + w_9\big(u(Y_{A2})\big) + w_{10}\big(u(v_A(g))\big) \quad (11)$$

U_B, U_C *are also calculated in the same way*
If $U_A > U_B, U_c$ *then Portfolio A is preferred rather than* B, C
The utility function will be assigned based on decesion makers preference (12)

4.3. Auto manufacturers and applying green practices in the presence of rivals (The case of End of life Vehicles)

4.3.1. Résumé

L'accomplissement d'une législation pertinente des produits en fin de vie (EOL), tenant en compte la prise en charge par les industriels des politiques en matière de développement durable ou d'une licence de service, peuvent influencer la valeur ajoutée et la réputation. Les avantages concurrentiels de l'exécution des directives des produits en fin de vie doivent être évalués dans le cadre du marché et de l'influence des interactions sur les intervenants. Le respect de la législation des produits en fin de vie est nécessaire à l'activité sur certains marchés. Cependant, les fabricants d'automobiles des États membres de l'Union Européenne doivent répondre aux exigences des directives en rapport avec le principe de la gestion des véhicules en fin de vie, par contre, pour les autres marchés il peut être un choix stratégique.

Dans cette étude, nous avons développé un modèle mathématique afin d'analyser le choix stratégique des constructeurs automobiles en réponse aux directives en rapport avec les véhicules en fin de vie comme résultat de l'interaction des différents compétiteurs sur le marché. Dans ce modèle, nous avons utilisé la théorie des jeux pour représenter l'évolution des interactions entre les fabricants automobiles.

Mots-clés: la législation EOL du véhicule, les fabricants d'automobile, théorie des jeux évolutionnaires, la concurrence

4.3.2. Abstract

Fulfilling the legislation pertinent to end-of-life (EOL) products, in addition to sustainability of manufacturers, or license to operation can lead to brands added value and reputation. The competitive advantages of performing the EOL directives need to be assessed in the market framework and the presence of interaction among players. Complying with EOL legislation is necessary for activity in some markets (auto manufacturers of Member States need to meet the requirements of European Union's EOL Vehicle Directives), however, for the other markets can be a strategic choice (for example, US auto manufacturers in the absence of national regulation for automobile disposal and waste). In this study, we developed a model in order to analyze the strategic choice of auto manufacturers in response to EOL directives as the result of interaction of competitors in the market. We used evolutionary game theory for modeling the game between automakers.

Keywords: EOL vehicle legislation, Auto manufacturers, evolutionary game theory, competition

4.3.3. Introduction

After experiencing a period of crisis in the automobile industry in US, this industry will return to their high pre-crisis levels. (Heymann, 2012) believes that in the longer term, an even higher sales volume is plausible. The author mentions the growing population figures (another 50 million people by 2030) and the primary importance of cars for US consumers as the main drivers for this growth rate. Vehicles affect the environment over their entire life cycle. Some of these effects occur at the end of their lives such as hazardous substance emissions, and disposals (Kanari et al., 2003).Addressing the environmental issues for End of life Vehicle (ELVs) raises a number of serious challenges for the industry. In the USA, there is no specific legislation regarding the management of ELVs. With respect to the broad landfill spaces with lower costs of waste disposal and lack of standard waste legislation for whole states, recycling industry has received much less interest (Konz, 2009). Automotive industry has an essential role in the recycling industries in US and auto manufacturers participate in the programs for improvement recycling management process. For example, Ford has purchased more than 25 vehicle recycling operations in the US, with more expected and has an experimental dismantling center in Germany (Staudinger and Keoleian, 2001). In the absence of the identical legislation in auto recycling, automotive manufacturers follow different practices in a variety range from changes in design to issue a guideline or standards. Each of these practices has also different impacts on the other players and even can change economic sustainability of ELVs business (Kumar & Sutherland, 2008). Moreover, automakers choice of applying eco design practices which improves the recycling rate of ELVs needs to be considered in the context of the market and interaction of other competitors. Hence for automakers there is two essential sources of uncertainty including market forces and future directives. Considering incomplete information and possibility of irrationality of players, it’s difficult for players to make sure that their choice of strategy is the best. Therefore, the evolutionary game theory is appropriate for analysis of the situation with these conditions. We used sensitivity analysis in order to show that how the type of eco design practices considering its costs and market forces such as the elasticity of demand to price can affect the stability of the game.

The rest of this paper is organized as follows: Section 4.3.2 provides a literature review. Section 4.3.3 introduces the model and formulation. Section 4.3.4 presents a numerical example, the results and the sensitivity analysis and finally in Section 4.3.5 we conclude with some remarks and insights for future researches.

4.3.4. Literature Review

4.3.4.1. Auto manufacturers and Eco practices

Design for environment (DfE) or Eco design strategy is one of manufacturer's efforts in order to integrate the environmental considerations into product and process design. There are different techniques and practices which can be used by manufacturers in DfE context. Material substitution, design for disassembly, design for recyclability and design for reusability are some of these practices. Each practice may have impacts on one or more stages of product life cycle as well as different effects on stakeholders and value creation framework. The motivations for designing align with environment come from different sources and pressures. The customer pressure, competitive forces and legislation are important reasons for companies in involvement in environmental efforts especially Eco efficiency design (Rose, 2000). The key drivers for Eco design practices and their effects on the manufacturer's behaviour can be shown as Figure 58.

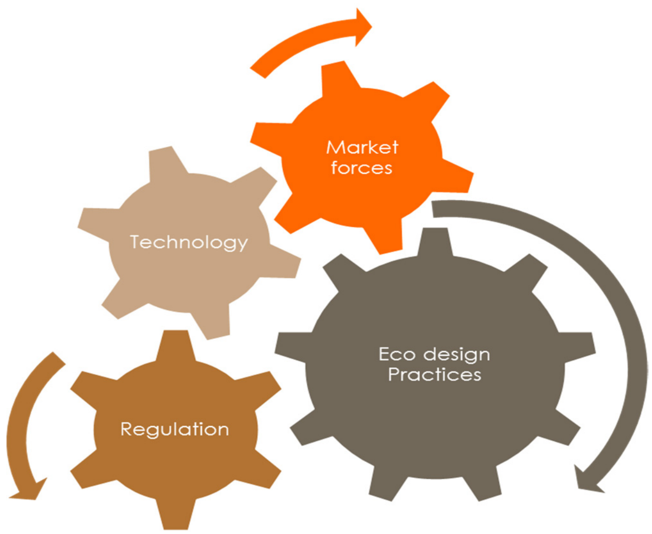


Figure 58 : The key drivers for Eco design practices

Waste management is crucial as landfills close and populations grow (Pohlen & Farris, 1992). Therefore, reducing landfilled material, maximizing recycling, and controlling hazardous materials are important challenges in the end of life treatment. Products with different characteristics experience distinct end-of-life strategies. Now, end-of-life treatment systems are developed by industry volunteers or as a reaction to legislation (Rose, 2000). One product which has considerable effect on the environment at the end of life is vehicle. Numerous voluntary programmes have been performed by car manufacturers. However, almost none of these programs meet the recovery percentages proposed by European directives (Gerrard & Kandlikar, 2007). Gerrard & Kandlikar, (2007) present an evaluation framework based on anticipated changes that could result from the ELV directives. These changes relate to three areas: (a) vehicle design, (b) level of ELV recovery, and (c) information provision. The authors brought the evidences from different automakers in applying different strategies regarding ELVs recycling. Why the different automakers apply the variety of strategies and what are the advantages and disadvantages of different strategies are questions, which should be addressed via an appropriate model, in order to understand the behavior of automakers. Different strategies, which may be applied by an automaker related to ELVs, have been shown in Figure 59.

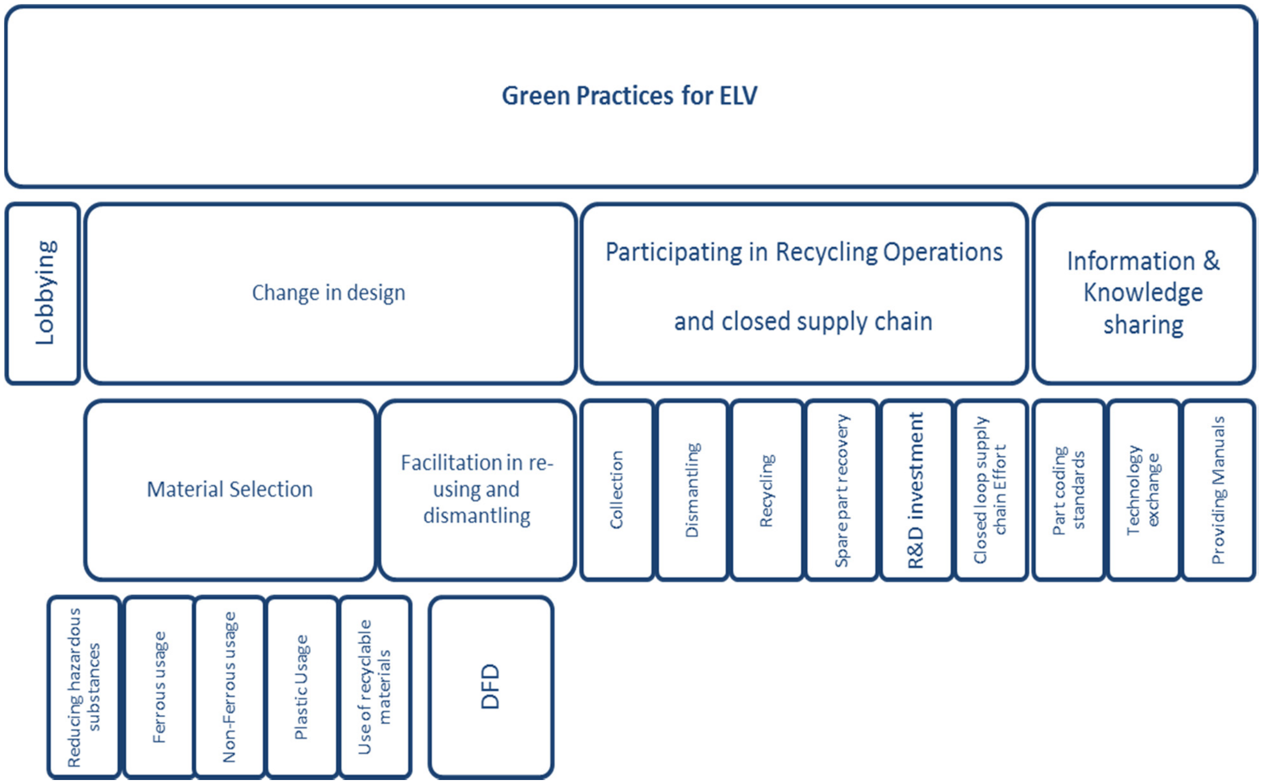


Figure 59 : Different strategies which can be applied by automakers

4.3.4.2. ELV in USA and regulations

Government policies regarding addressing different phases of ELVs recycling process especially those in improving recycling rate can affect new technologies, market share of automotive manufacturers, the profit of dismantlers and shredders and even the sustainability of the overall business.

Technical requirements for car design and minimum reuse and recovery rates for end-of-life vehicles are recent European Union directive on ELVs (Ferrao et al., 2006). In order to meet this directive, more changes are needed in recycling infrastructures and manufacturers actions. Hence complying with this directive raises some challenges for the automaker and other key players in recycling infrastructures. The requirements of EU directive on ELV are reducing total waste, organizing waste collection and treatment, meeting the target of re-use and recovery (85 % no later than 1 January 2006 and 95 % no later than 1 January 2015), and facilitating dismantling process via providing manuals and information and evaluation of progress through reports. Around 15 million cars and trucks reach the end of their useful life in the United States each year (Ferrao et al., 2006). Konz (2009) with studying the success and criticism of EU directives and current directives in US, proposed a framework for future directives in relation to ELVs in US. According to this reference in USA, no national regulation exists for the disposal of automotive waste and Individual States are free to adopt inconsistent regulations, or waive regulation completely. While the EU ELV Directive has a number of shortages, it can be considered as an initial model for uniform, federally mandated ELV legislation in USA. Three areas for future regulation in US can be explained as shown in Figure 60.

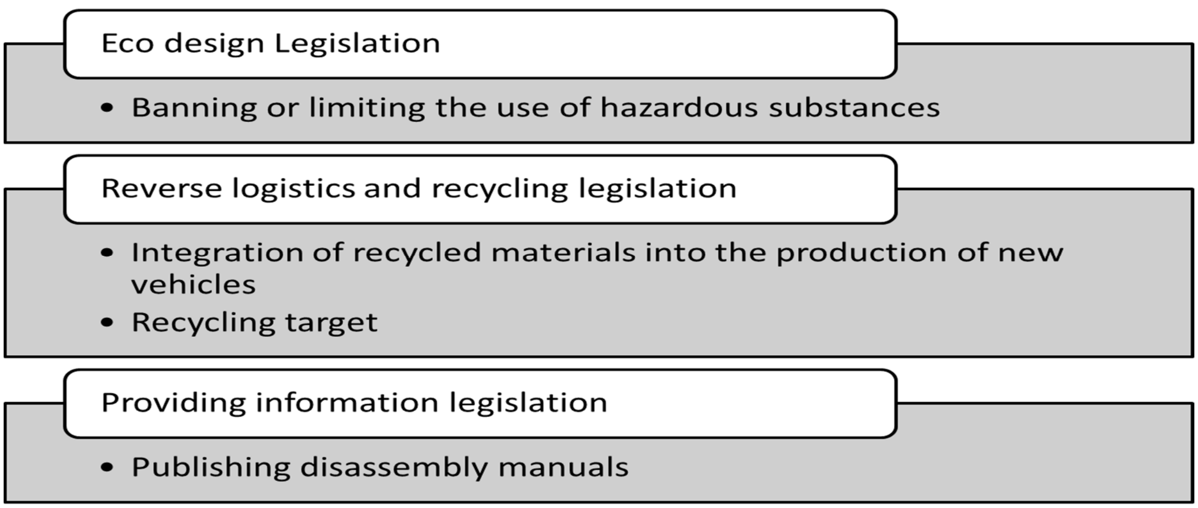


Figure 60 : Three areas for future regulations in USA

4.3.4.3. Evolutionary game theory

In conventional game theory, there are three assumptions: (1) rational behavior of all the agents, (2) complete sharing of empirical information, (3) all the agents have common knowledge of these assumptions (Barari et al., 2012). As in the real world, considering these assumptions is difficult or even impossible, applying evolutionary game theory can bring the most advantages for modeling the behaviors of players. In Evolutionary game theory instead of directly calculating properties of a game, populations of players using different strategies are simulated, and a process similar to natural selection is used to determine how the population evolves. Varying degrees of complexity are required to represent populations in multi-agent games with differing strategy spaces. Zhu & Dou (2007) used evolutionary game theory in order to investigate the games between governments and core enterprises in greening supply chains. Barari et al. (2012) applied evolutionary game for analyzing the game between the producer and the retailer to adjudicate their strategies to trigger green practices with the focus on maximizing economic profits. Considering incomplete information and possibility of irrationality of game players, it is difficult for players to make sure that their choice of strategies is the best. Hence the evolutionary game theory is appropriate for analysis of the situation with these conditions. We used an extensive form of evolutionary game theory for modeling the game among automakers in performing the ELVs strategies.

4.3.5. Modeling Game between Automakers

For analysis of the game among automakers, we considered two groups of players. First group is dominant automakers in US automotive industry (Such as Big Three: Ford, General Motors, and Chrysler) the second group of player is non-dominant (fringe) automakers in US automotive market. Geçkil & Anderson (2009) also used the classification of domestic automakers and non-domestic automakers with concentration on light trucks, non-domestic automakers with concentration on passenger cars for analysing the game among government and automakers in for regulations regarding CAFE (corporate average fuel economy) standards in US.

There are two general strategies in this game; cooperation and competition. Cooperation for dominant automakers means accepting the associated costs of applying ELVs eco practices with no change in their price. Competition for this group of automakers means increasing the price and profiting from raising rivals cost. Salop and Scheffman (1983) explained in their study a novel concept named «raising rivals' costs". The authors showed that firms could gain market power by conducting this strategy. They brought a formal analysis which illustrates how applying this strategy for a dominant firm can lead to profitability. On the other side, cooperation for non-dominant automakers is applying one of ELVs strategies and competition means not following ELVs strategies. We assumed that there is not any regulation with respect to ELV in the market and applying ELV practices is not obliged. The structures of the game and payoff matrix have been shown in Figure 61 and Table 19 respectively. First we need to address the pure strategies for two players. Table 20 illustrates this list.

Table 19 : Pure strategies for two players

Automaker A	Automaker B
SA1: Cooperation	SB1: If Automaker A selects Cooperation: Cooperation; If Automaker A selects Competition: Cooperation
SA2: Competition	SB2: If Automaker A selects Cooperation: Cooperation; If Automaker A selects Competition: Competition
	SB3: If Automaker A selects Cooperation: Competition; If Automaker A selects Competition: Cooperation
	SB4: If Automaker A selects Cooperation: Competition; If Automaker A selects Competition: Competition

(Salop & Scheffman, 1983) explain that advertising expenditure and R&D races can be used to raise rivals' costs. The natures of eco practices particularity in the design category are like R&D investments in term of uncertainty, the essential role of technology and market effects. Applying one eco design practices can increase the average cost of manufacturer. This expenditure as performed by an efficient firm (we supposed that dominant firms are cost efficient) is tolerable, and it must be matched in effective intensity by less efficient rivals (fringe firm). In this case, no matter that applying the eco design practice can lead to the direct benefit for the dominant firm (consumer satisfaction, image benefit or etc.), the dominant firm can advantage from the consequence of this strategy. Disadvantage competitors can provide a benefit that goes beyond its costs if the strategy permits the dominant firm to increase the price or market share. For analyzing the game, we used the basis of formal analyzing provided by Salop and Scheffman (1983). We changed some assumptions and made some changes in order to adapt it with the game of automakers in this study.

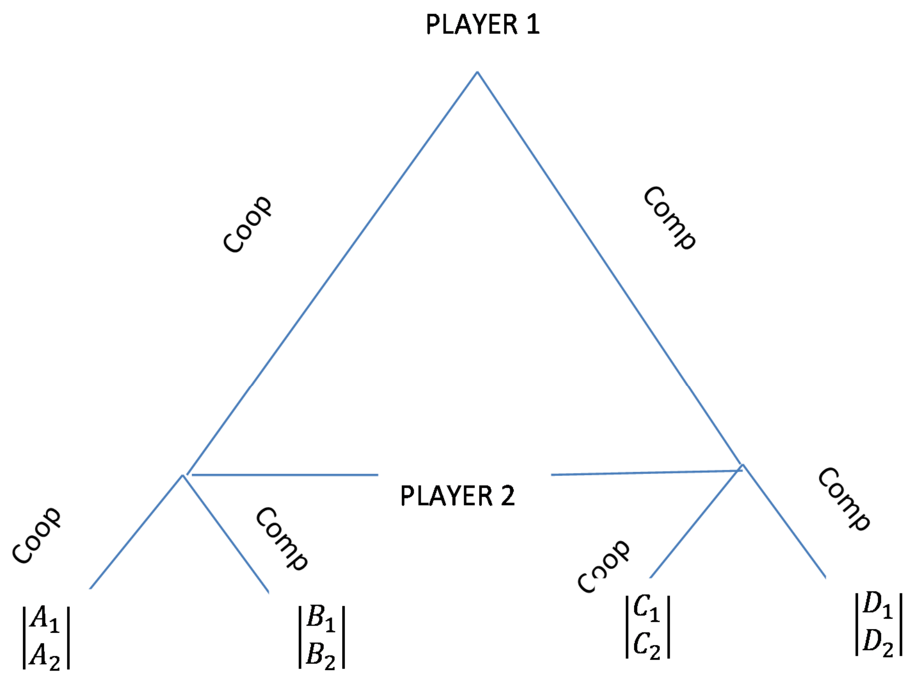


Figure 61 : The structure of Game

Table 20 : The pay-offs of the players

		Automaker B			
Automaker A		Coop/ Coop	Coop/Comp	Comp/ Coop	Comp/Comp
	Cooperation	(A1, A2)	(A1, A2)	(B1, B2)	(B1, B2)
	Competition	(C1, C2)	(D1, D2)	(C1, C2)	(D1, D2)

Table 21 : The variables definition

Variables	Definition
$\boldsymbol{C(\alpha)}$	The cost for applying strategy α
$\boldsymbol{CA}$	The cost of Automaker A
$\boldsymbol{CB}$	The cost of Automaker B
$\boldsymbol{R(\alpha)}$	The direct revenue from applying strategy α
$\boldsymbol{\varepsilon_{D,P}}$	The elasticity of demand to price
$\boldsymbol{\varepsilon_{S_B,P}}$	The elasticity of supply of automaker B
$\boldsymbol{S_B}$	The supply of automaker B
$\boldsymbol{S_B}$N	The new supply of automaker B
$\boldsymbol{x}$	The market share of automaker A
$\boldsymbol{y}$	The market share of automaker B
$\boldsymbol{P}$	The price
$\Delta\boldsymbol{y}$	The change in supply by automaker B
$\boldsymbol{D}$	The demand of market
$\boldsymbol{D}$N	The new demand of market
$\Delta\mathbf{p}$	The change in price by automaker A

In this model, the automakers A act as a price leader. The demand of the market is D and SB is supply of automakers B, which follows by collectively setting output y. The dominant firm produces at the point x on the residual demand curve R which is equal to (D- SB). For calculation of pay-off of each population of player and market share, we used the principle of dominate firm model.

According to the definition of the dominant firm model in oligopoly context, the dominant firm sets prices which are taken by the fringe firms in defining their profit maximizing levels of production. The demand curve for the dominant firm is determined by subtracting the supply curves of all the small firms from the industry demand curve. After estimating net demand curve, the dominant firm maximizes profits by following the typical rule of producing, where marginal revenue equals marginal costs. The small firms maximize profits by acting as perfectly competitive firms equating price to marginal costs (Samuelson, & Marks, 2008).

The formulation of the problem has been shown via equations 4.3.1-4.3.21. Equation 4.3.1 and 4.3.2 represent the continuous replicator dynamic of the game. The fitness of an individual playing strategy SAi will be (Ay$\vec{y}$)i. The average fitness of the first population will be x$\vec{x}^T$Ay$\vec{y}$. Similarly the fitness of strategy SBi will be (By$\vec{y}$)i, and the average fitness for the second population will be x$\vec{x}^T$Ay$\vec{y}$. The pay-off matrices are written as 4.3.3 and 4.3.4. The pure strategies for two populations are presented as 4.3.5 and 4.3.6. We used the standard Jacobian Matrix (J) for evaluating the stability of an equilibrium strategy pair and obtain the evolutionary stable strategy (ESS) values. Equation 8 shows the trace of J matrix and conditions for finding ESS.

$$x\dot{x}_{\imath=}xx_i((A\overline{y\vec{y}})_1-\overline{x\vec{x}}^T\overrightarrow{Ay\ y}) \quad (4.3.1)$$

$$y\dot{y}_{\imath=}yy_i((B\overline{x\vec{x}})_1-\overline{y\vec{y}}^T\overrightarrow{B\ xx}) \quad (4.3.2)$$

$$A=\begin{pmatrix} A_1 & A_1 & B_1 & B_1 \\ C_1 & D_1 & C_1 & D_1 \end{pmatrix} \quad (4.3.3)$$

$$B=\begin{pmatrix} A_2 & C_2 \\ A_2 & D_2 \\ B_2 & C_2 \\ B_2 & D_2 \end{pmatrix} \quad (4.3.4)$$

$$x = \binom{xx}{1 - xx} \quad (4.3.5)$$

$$yy = \begin{pmatrix} yy_1 \\ yy_2 \\ yy_3 \\ 1 - (yy_{1+}yy_{2+}yy_3) \end{pmatrix} \quad (4.3.6)$$

$$= \begin{bmatrix} \frac{\partial \dot{xx}}{\partial xx} & \frac{\partial \dot{xx}}{\partial yy_1} & \frac{\partial \dot{xx}}{\partial yy_2} & \frac{\partial \dot{xx}}{\partial yy_3} \\ \frac{\partial \dot{yy_1}}{\partial xx} & \frac{\partial \dot{yy_1}}{\partial yy_1} & \frac{\partial \dot{yy_1}}{\partial yy_2} & \frac{\partial \dot{yy_1}}{\partial yy_3} \\ \frac{\partial \dot{yy_2}}{\partial xx} & \frac{\partial \dot{yy_2}}{\partial yy_1} & \frac{\partial \dot{yy_2}}{\partial yy_2} & \frac{\partial \dot{yy_2}}{\partial yy_3} \\ \frac{\partial \dot{yy_3}}{\partial xx} & \frac{\partial \dot{yy_3}}{\partial yy_1} & \frac{\partial \dot{yy_3}}{\partial yy_2} & \frac{\partial \dot{yy_3}}{\partial yy_3} \end{bmatrix} \quad (4.3.7)$$

$$tr(J) = \left[\frac{\partial \dot{xx}}{\partial xx} + \frac{\partial \dot{yy_1}}{\partial yy_1} + \frac{\partial \dot{yy_2}}{\partial yy_2} + \frac{\partial \dot{yy_3}}{\partial yy_3}\right] \quad (4.3.8)$$

If $\det(J) > 0, tr(J) < 0, the\ soloution\ is\ ESS\ of\ the\ Game$

Equations 4.3.9-4.3.32 show the pay-off matrices elements and the used variables are defined in table 21.

The first term in equation 4.3.9, 4.3.10, 4.3.13, 4.3.14, 4.3.17, 4.3.18, 4.3.25 and4.3. 26 is the profit of the automaker without applying ELV practice. The second term (if any) shows the profit as the result of applying one ELV practice which called as strategy α. The equation 4.3.11 presents market share of automakers B, which is derived from price to marginal costs. Equation 4.3.12 shows the market share of population A which is obtained from residual demand curve. In this case, we assumed two players select cooperation. Equation 4.3.15 and 4.3.16 shows the market share of each player when A selects cooperation and B selects competition. When A select competition and B select cooperation, benefits from raising rivals costs with increasing the price. In this case, the market share of B will be decreased. Equations 4.3.19 and 4.3.20 show these changes. As the price will be changed, it is necessary to consider the effect of demand elasticity and supply elasticity of B as the result of this increasing in price. The equations 4.3.21 and 4.3.22 represent new market demand and supply of B respectively. The market share of two players has shown in equations 4.3.23 and 4.3.24. When two groups of population select the competition as a strategy, the changes in price, demand, supply of B and their market shares are presented in equations 4.3.27-4.3.32. It should be noted that, for simplicity, we assumed the linearity for supply, marginal cost and marginal revenue curves. However the formulas can be modified according to the real curves which suggests for future studies.

$$A_1 = (P - C_A)x + \{R_A(\alpha) - C_A(\alpha)\} \tag{4.3.9}$$

$$B_1 = (P - C_B)y + \{R_B(\alpha) - C_B(\alpha)\} \tag{4.3.10}$$

$$y = \left\{\frac{C_B(\alpha)}{P - C_B}\right\} \tag{4.3.11}$$

$$x = \{D - (y)\} \tag{4.3.12}$$

$$A_2 = (P - C_A)x + \{R_A(\alpha) - C_A(\alpha)\} \tag{4.3.13}$$

$$B_2 = (P - C_B)y \tag{4.3.14}$$

$$y = \{S_B\} \tag{4.3.15}$$

$$x = \{D - (y)\} \tag{4.3.16}$$

$$A_3 = ((P + \Delta P) - C_A)x + \{R_A(\alpha) - C_A(\alpha)\} \tag{4.3.17}$$

$$B_3 = ((P + \Delta P) - C_B)y + \{R_B(\alpha) - C_B(\alpha)\} \tag{4.3.18}$$

$$\Delta P = \frac{C_A(\alpha)}{(D - S_B)} \tag{4.3.19}$$

$$\Delta y = \frac{C_B(\alpha)}{P - C_B} \tag{4.3.20}$$

$$DN = D - \varepsilon_{D,P}\Delta P \tag{4.3.21}$$

$$S_B N = S_B - \varepsilon_{SB,P}\Delta y \tag{4.3.22}$$

$$y = \{S_B N - \Delta y\} \tag{4.3.23}$$

$$x = \{DN - y\} \tag{4.3.24}$$

$$A_4 = ((P + \Delta P) - C_A)x + \{R_A(\alpha) - C_A(\alpha)\} \tag{4.3.25}$$

$$B_4 = ((P + \Delta P) - C_B)y \tag{4.3.26}$$

$$\Delta P = \frac{C_A(\alpha)}{(D - S_B)} \tag{4.3.27}$$

$$DN = D - \varepsilon_{D,P}\Delta P \tag{4.3.28}$$

$$S_B N = S_B - \varepsilon_{SB,P}\Delta y \tag{4.3.29}$$

$$\Delta y = S_B N(\frac{\Delta P}{P}) \tag{4.3.30}$$

$$y = \{S_B N - \Delta y\} \tag{4.3.31}$$

$$x = \{DN - y\} \tag{4.3.32}$$

4.3.6. Numerical Example and Discussion

In this section, we represent a numerical study and some scenarios discussion to provide managerial insights for decision makers. The used value for each variable in the numerical example is shown in Table 22. We assumed that two populations of players (automakers A and B) produce a certain product in one segment, which can be comparable.

Mathematical evaluation of ESS is done to identify the optimal strategy set that conveys the maximum economic benefit. This formulation has been coded in Matlab. The result is shown in Table 23. Automakers A play 0.15% of time cooperation strategy and 0.85% of time competitive strategy while Automakers B always play S_B1 which means “If Automaker A selects Cooperation; Cooperation; If Automaker A selects Competition, Cooperation”.

Table 22 : The values for numerical example

Variables	Value
$C(\alpha)$	25 for A and 30 for B
CA	4
CB	6
$R(\alpha)$	40 for A and 35 for B
$\varepsilon_{D,P}$	5
$\varepsilon_{S_B,P}$	3
S_B	20
P	20
D	100

Table 23 : The ESS of players

S_A1	S_A2	S_B1	S_B2	S_B3	S_B4
0.15	0.85	1	0	0	0

As we discussed in the previous section, when automaker A selects competition strategy, it benefits from raising rival costs with increasing the price and market share.

The change in the residual demand curve depends on the elasticity of demand as well as the elasticity and shift of the fringe supply curve. As demand elasticity decreases, a given reduction in fringe supply causes a larger price rise. At the other side, if demand is perfectly elastic, residual demand does not increase at all (Salop and Scheffman, 1983). Hence assessing the effect of demand elasticity and supply elasticity of population B on strategies of players is essential. With this sensitivity analysis, we can observe the effect of market forces.

As shown in Figure 62, 63 with increasing in demand elasticity and supply elasticity for player B, the player A prefer to play competition rather than cooperation and the willingness of player B for playing cooperation after competition will be decreased. As well as the willingness of player B for playing competition after cooperation and cooperation after competition will be increased. Figure 64 shows these changes in 3D plot obviously.

(Kuhn, 2005) introduces environmental orientation of the market as the key parameter in assessing the green market context. He defined the environmental orientation of the market as the ratio of environmental elasticity of demand to price elasticity. The author concludes that high quality dominance with respect to both profit and market share implies an environmental orientation of the market which is sound relative to the cost of environmental performance (p.161).

In this case, it means that when environmental orientation of the market is strong then consumers can pay for cars with a high rate of recycling and less EOL effect on the environment. In other extreme, in the market which consumers do not care the green performance of their choices, the translated eco practices costs in the price of car, leads to decreasing the demand and consequently market share of manufacturers.

In order to analyze the different choice of manufacturers in term of which eco practices needs to be selected, we focused on associated costs and direct benefit of applying different eco practices as a measure. Figure 65, 66 shows the change in stable strategy of players based upon the change in direct revenue and the costs associated of implementing eco practices. When the cost of applying the ELV practices increases the willingness of player A for playing cooperation strategy decreases slightly but, obviously with these changes, player B prefers to play competition and not applying ELV.

For fringe firms, the associated cost of eco practices particularly those, which need more investing in R&D and human resources, are not tolerable. So they prefer to apply the practices with less cost such as preparation of manuals or other information provisions.

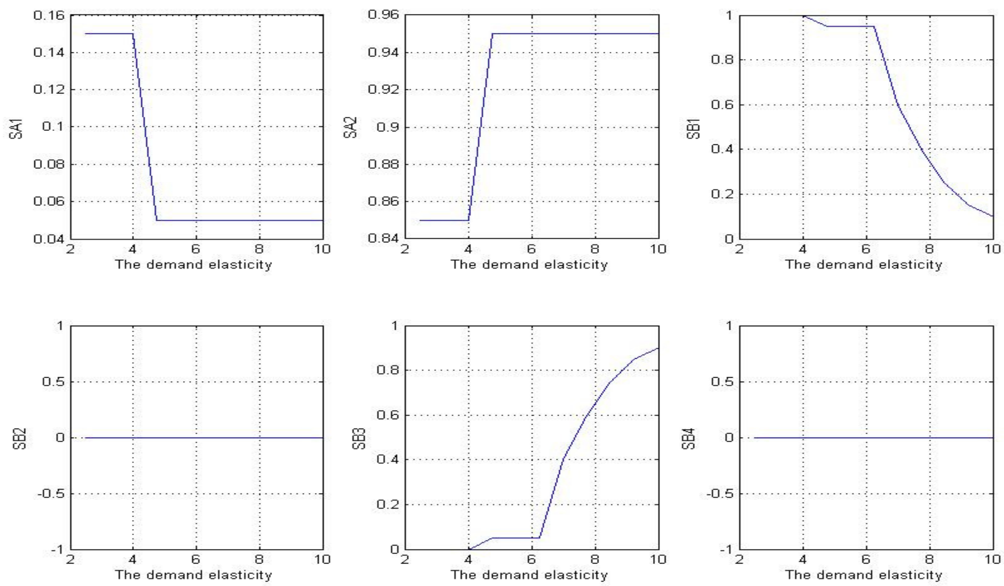


Figure 62 : The change in ESS of players based upon the change in demand elasticity

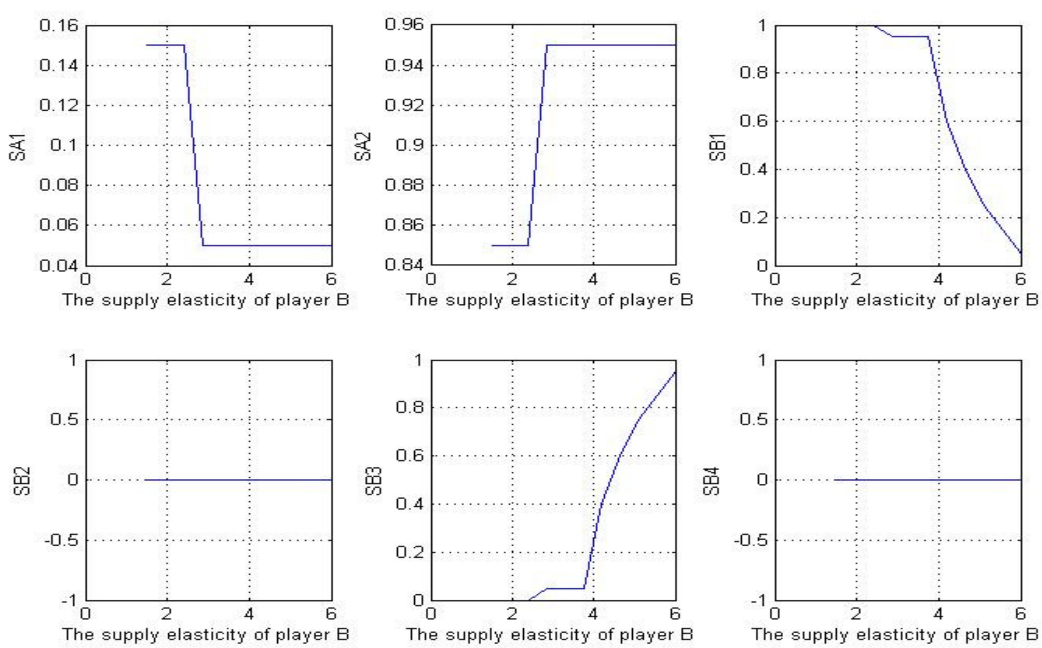


Figure 63 : The change in ESS of players based upon the change in supply elasticity

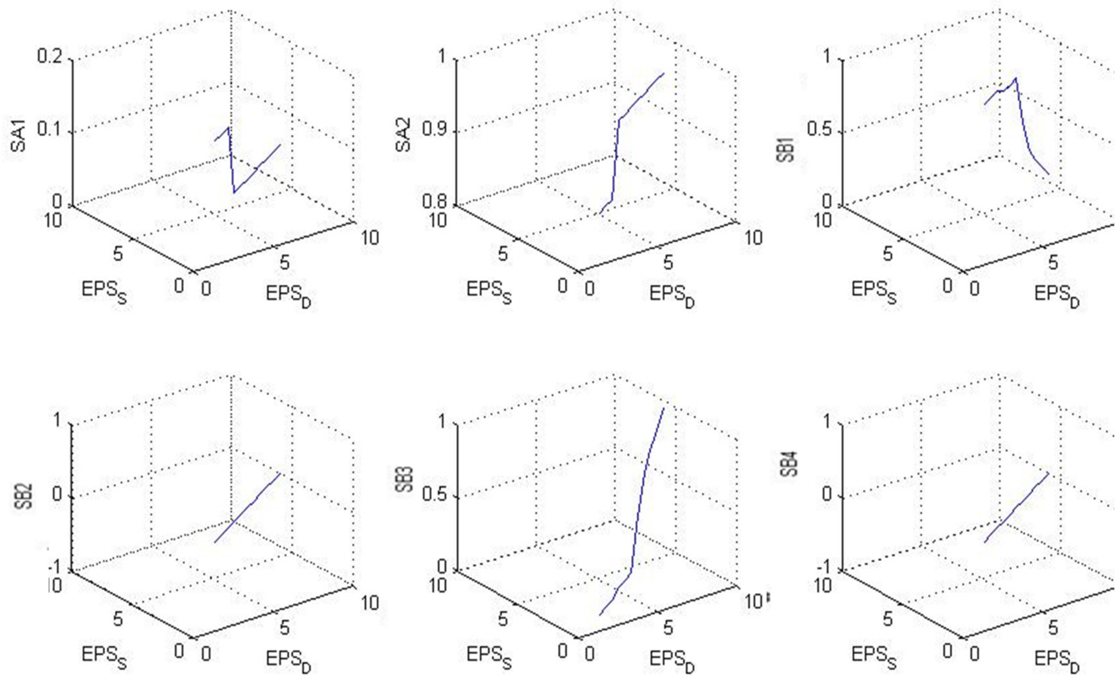


Figure 64 : The change in ESS of players based upon the demand elasticity and supply

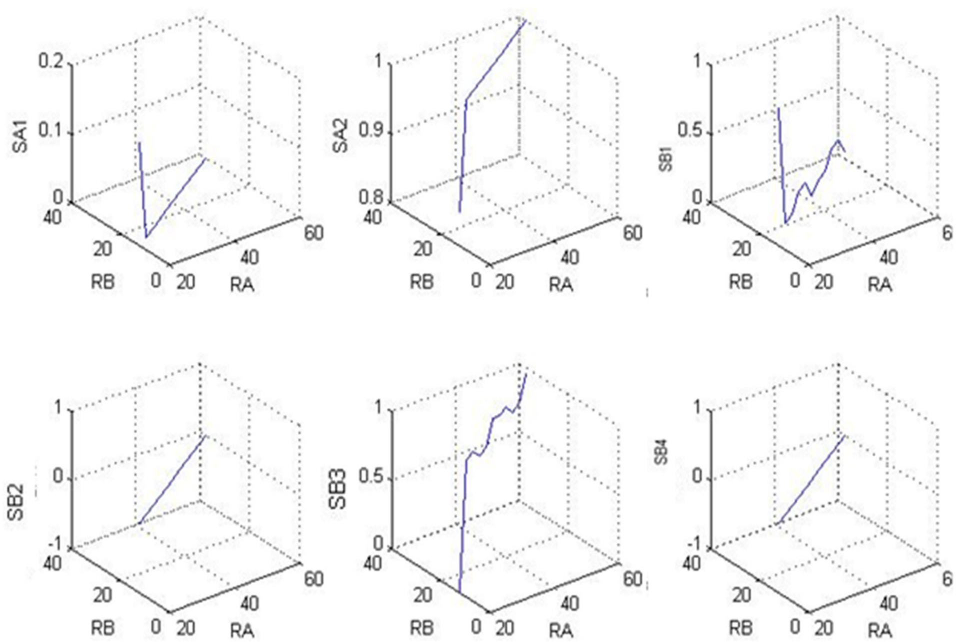


Figure 65 : The change in strategy of players based upon the change of direct revenue from applying the eco practices

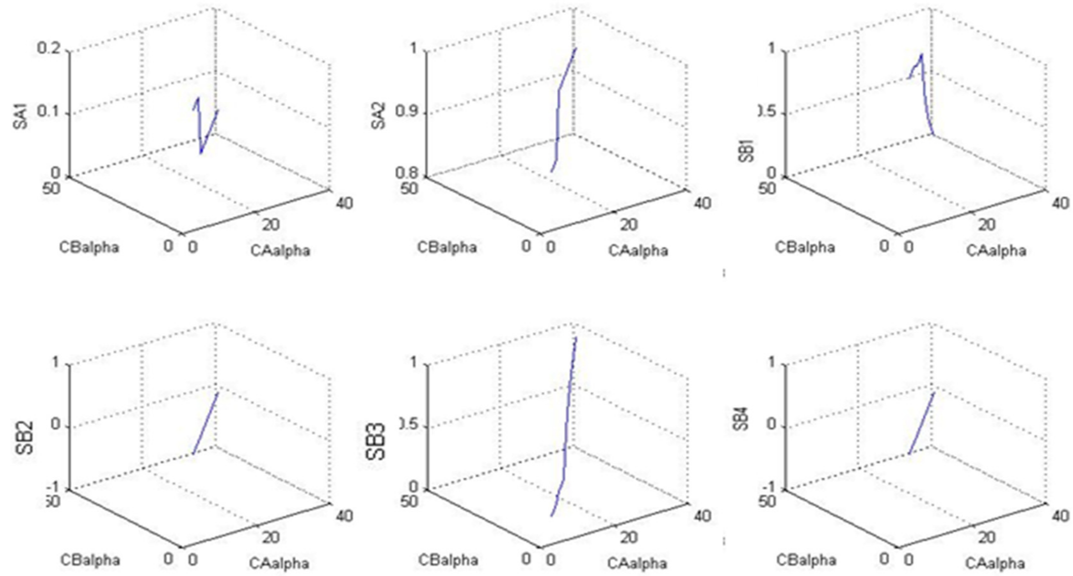


Figure 66 : The change in strategy of players based upon the change of costs of applying the eco practices

4.3.7. Conclusion and future research

This paper proposed an evolutionary game model in order to analyze the behavior of automakers in applying the eco practices in the presence of competition. The result shows that when we have two populations of players including dominant firms and fringe firms; the market elements such as demand elasticity and supply elasticity are important parameters in stable strategy of the game. Furthermore, the choice of eco practices with respect to direct revenue and associated costs are considerable. We assumed a market with no regulation regarding ELV in order to predict the behavior of players; however the different scenarios of future regulations can be addressed in a separate study.

Moreover in analyzing the market forces, we did not consider the effect of loyalty of consumers, taste of consumer and other factors in market. We propose considering these uncertain factors as further study. The influence of technology, which can change the cost and revenue of implementing the eco practices, also can be assessed in future studies.

References

Barari, S. et al., (2012)," A decision framework for the analysis of green supply chain contracts: An evolutionary game approach" Expert Systems with Applications 39 ,2965–2976

Daniels, E. J., Carpenter Jr, J. A., Duranceau, C., Fisher, M., Wheeler, C., & Winslow, G. (2004)," Sustainable end-of-life vehicle recycling: R&D collaboration between industry and the US" DOE. JOM, 56(8), 28-32.

Ferrao, P., Nazareth, P., & Amaral, J. (2006)" Strategies for Meeting EU End of Life Vehicle Reuse/Recovery Targets". Journal of Industrial Ecology, 10(4), 77-93.

Geçkil, I. K., & Anderson, P. L. (2010). "Applied game theory and strategic behavior". Chapman & Hall.

Gerrard , J., Kandlikar.M.(2007), "Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on 'green' innovation and vehicle recovery", Journal of Cleaner Production 15 -17e27

Heyman, E.,(2012), "US car market: Returning to its previous size : retrieved from : www.dbresearch.com

Kanari,N., Pineau, J.-L. and Shallari, S. (2003) "End-of-Life Vehicle Recycling in the European Union", Journal of the Material, pp. 15-19

Konz, R. J., (2009) "The End-of-Life Vehicle (ELV) Directive: The Road to Responsible Disposal", 18 Minn. J. Int'l L. 431

Kuhn, M. (2005). "The greening of markets: product competition, pollution and policy making in a duopoly". Edward Elgar Publishing.

Kumar, V. and Sutherland, J.W. (2008) "Sustainability of the automotive recycling infrastructure: review of current research and identification of future challenges", Int. J. Sustainable Manufacturing, Vol. 1, Nos. 1/2, pp.145–167.

Pohlen, T. L., Farris, M. T. (1992). “Reverse logistics in plastics recycling, International Journal of Physical, Distribution and Logistics Management 22(7): 35-47.

Rose, C.M. (2000). “Design For Environment: A Method for Formulating Product End-Of-Life Strategies, Ph.D. Thesis, Stanford University

Salop, S. C., & Scheffman, D. T. (1983). “Raising rivals' costs. The American Economic Review, 73(2), 267-271.

Samuelson, W. F., & Marks, S. G. (2008). Managerial economics. John Wiley & Sons.

Staudinger,J.& Keoleian,G., (2001),” Management of End-of Life Vehicles (ELVs) in the US” ,a report of the Center for Sustainable Systems,Report No. CSS01-01

Zhu,Q. & Dou,Y.,(2007),” Evolutionary Game Model between Governments and Core enterprises in Greening Supply Chains’,Systems Engineering - Theory & Practice,Volume 27, Issue 12

4.4. Sustainable Approach to Aircraft Maintenance at Design Stage

4.4.1. Résumé

Cet article introduit un cadre conceptuel intégré pour l'optimisation des activités de maintenance d'avions à l'étape de la conception tenant compte de la fiabilité, de la performance économique, environnementale et sociale. Pour cela, nous proposons un guide pratique pour l'application de ce cadre conceptuel pour un moteur d'avion. En outre, nous mettons en évidence les principales contributions qui prennent en compte l'aspect développement durable pour les opérations de maintenance dans la phase de conception des avions. Nous analysons dans cette recherche plusieurs domaines clés qui proposent des idées pour les chercheurs et les fabricants.

Mots-clés: Entretien d'avions, étape de conception, durabilité

4.4.2. Abstract

This paper proposes an integrated conceptual framework for optimization of aircraft maintenance activities at the design stage considering reliability, economic, environmental and social performance. A practical guideline for application of this framework for an aircraft engine is illustrated. After studying the available scientific literature on the problem, we highlight the main contributions of past research and the existing gap of considering a sustainability approach to aircraft maintenance operations at the design stage. We uncover the main areas which provide insights for researchers and manufacturers.

Key Words: Aircraft Maintenance, Design stage, sustainability

4.4.3. Introduction

There are two types of aircraft maintenance: preventive or scheduled maintenance, which is performed at regular intervals to restore and maintain the system in desirable condition and the other one is un-scheduled maintenance, which is applied in order to correct the problems in the system. All of these activities have essential environmental impacts including wastes and end-of-life (EOL) parts during the maintenance operations. According to life cycle assessment (LCA) of commercial aircrafts, the environmental impact of the maintenance phase is significant and cannot be neglected [9, 24]. Corporate social responsibility forces aircraft manufacturers take into account these impacts and develop some solutions in order to minimize the environmental impacts of the maintenance phase. Moreover, maintenance steering groups (MSG) highlight the importance of considering safety and reliability as well as economic benefits in developing the maintenance tasks. Therefore, the aircraft manufacturers need to develop efficient and practical solutions to meet the requirements of safety and reliability. But at the same time, they need to minimize life cycle costs while preventing or limiting harmful impacts to the environment. This goal can be achieved with defining objectives including making longer life parts (prevention of part replacements) and limiting harmful impacts to the environment (wastes and EOL parts) during maintenance operations without any adverse effects on safety and performance. Furthermore, considering the social impacts as the result of maintenance actions are also essential in order to achieve the sustainable development. In this paper, we propose a framework for optimization of maintenance operations considering, economic, environmental, reliability and social performance. This paper is organized as follows: section 4.4.2 provides a literature review, section 4.4.3 illustrates the framework for engine maintenance in the sustainable development context and section 4.4.4 concludes with some remarks and potential future research efforts.

4.4.4. Literature review

4.4.4.1. Sustainable manufacturing

Recently, extensive attention to sustainable development has started becoming an essential aspect in the aviation industry. Aircraft manufacturers have reacted to this situation and recognized the importance of focusing their efforts to integrate sustainable development policies into their core business strategies. However, the effectiveness and the efficiency of such efforts have been in question because systematic approaches to support such activities are limited [1]. Design for environment (DfE) or Eco design strategy is one of these efforts in order to integrate the environmental considerations into product and process design. There are different techniques and practices which can be used by manufacturers for DfE. Material substitution, design for disassembly, design for recyclability, design for reusability are some of these practices [25]. Based on literature reviews, DfE tools and methodologies are required to be more developed [2]. Furthermore, the stakeholders, life cycle approach and multi-criteria decision analysis are needed to be considered in an integrated eco design approach [3]. The key elements of DfE are eco efficiency metrics, eco efficient design practice and evaluation method [5]. Among these key elements, the relevant metrics and practices for maintenance are shown in Figure 67.

4.4.4.2. Aircraft Maintenance

In aircraft maintenance, only 11 percent of aircraft components would benefit from setting interval checking with respect to their wear out conditions [6]. The failure rate for these items can be predicted and scheduled maintenance is a good solution in order to prevent the failures for these items. But for the other 89 percent of items, as the failures occur, the scheduled maintenance or preventive maintenance cannot be applied and un-scheduled maintenance is required to correct the problems [7].

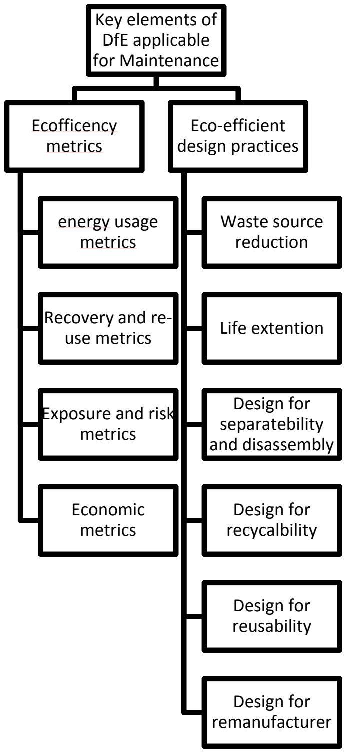


Figure 67 : Key elements of DfE application for maintenance

4.4.4.3. Life cycle Impact of maintenance Phase

In this part, we provide a review of the environmental impact of maintenance operations and the LCA. According to EPA/310-R-97-001, aircraft maintenance is the function of three factors: hours of flight time, number of landing and take-off cycles and calendar length of time from prior maintenance [8]. This EPA document provides a list of maintenance operations and the potential impacts of these operations on the environment. Another study was performed of the life cycle environment inventory of passenger transportation in the US [9]. The author used EPA/310-R-97-001 category, in order to evaluate the impact of the maintenance phase. According to the study outcome, the impact of vehicle maintenance is comparable with vehicle manufacturing and is not negligible. However, the result of this study is based on the costs of different maintenance operations and the effect of part replacement has not been considered. In the vehicle and passenger car, the maintenance phase in the LCA is considered in different approaches. For example, a study of environmental improvement of passenger cars considers the manufacturing of spare parts such as oil, tire and battery as well as the maintenance and repairing operations [10]. According to the report of product sustainability index of Ford [11], three parts in maintenance operations are considered: maintenance material production, waste and other maintenance processes. However, the effect of oil and the other sections have been excluded from the study due to the lack of information [11]. In the study of analyzing the life-cycle of new automobile technologies, it has been specified that "Maintenance energy encompasses all energy that is used to replace vehicle parts or liquids, throughout the entire vehicle life. As there is virtually no information available, we have neglected this stage of energy use and emissions. However, the associated error should be small, as energy use and emissions are likely significantly smaller than material production and vehicle assembly" [12]. Therefore, according to existing literature, there is not a unique approach for considering the impact of maintenance phase in life cycle assessment. And, it seems that parts and components replacement, repairing operations and waste during maintenance operations are three important categories of maintenance and repairing phase in order to be considered as the environmental impacts.

4.4.4.4. Optimization of Maintenance process

Engineers and mathematicians have considered the maintenance optimization area because it's an interesting area for modeling and exploiting their analysis [13]. However, as the result of complexity of these models and lacking of data, application is limited. The papers which address maintenance optimization in aerospace context can be classified in two categories. The first category of studies is related to optimization of overhaul planning and manpower planning that usually utilize job scheduling and planning methods [14],[15],[16] cited in [13]. The second category considers maintenance optimization at design stage which is also limited. The study in [17] focuses on the large engine maintenance techniques and proposes some solutions in order to decrease the maintenance costs. The solutions are classified in two categories of planning and developing new techniques. In planning, they explained that how setting time and range of engine maintenance can lead to reducing the engine maintenance cost. In developing techniques, they demonstrated some parts repair techniques which lead to part repair costs and saving parts which were bound to be scrapped. An optimization model using genetic algorithm is developed in order to support maintenance infrastructure [18]. The objective of this model is optimization of maintenance and maintainability during the design stage of the equipment for minimum life cycle cost (LCC) or minimum total cost of ownership (TCO). They developed the model based on modular and multi echelon perspective.

4.4.4.5. Stakeholders view

A manufacturer with sustainable organization culture requires identifying not only the stakeholders and their expectations but also interdependencies and synergies in stakeholder's network to maximize the value considering environmental, economic and social requirements [4]. Thus, for sustainable eco design strategy, in addition to considering the value outcomes of implementation an eco-design technique, its impact on stakeholders network is also needed to be taken into account. In order to have a sustainable approach to maintenance in aerospace context, we need to identify the stakeholders, their needs and expectation and interaction among them. Figure 68 shows the different stakeholders in aircraft maintenance considering life cycle approach.

Figure 68 : Stakeholders in aircraft maintenance

4.4.5. Engine maintenance

4.4.5.1. Context

The engine maintenance covers 30% of the total cost of the aircraft maintenance. Moreover, reduction of shop maintenance cost is important for reduction of the operational cost of an aircraft because it would be approximately 50-60% of the total cost [17]. Hence considering the different aspects of engine maintenance at design stage is crucial. The complex equipment has modular design (multi indenture design) and maintenance is carried out at multiple echelons [18]. The modular structure of aircraft engine has three levels: line replaceable unit level, shop replicable unit and part. Work done in [18] also used engine (LRU) case study including 10 modules (SRU) with 22 parts spread between these modules in order to optimize Level of Repair Analysis (LORA).The process of engine maintenance is consisted of disassembly, cleaning, repair, assembly and test [17]. In each part of this process there is a potential for optimization particularly at design stage. In the disassembly and assembly phases, design for maintainability, in the cleaning and inspection, information provision or providing manual, in the repair phase, choosing techniques, level of operation and decision regarding part destination (reusing, remanufacturing or disposal) and finally for the testing phase, providing information can be considered as the areas for optimization and improvement.

4.4.5.2. The framework for Multi objective and hierarchical optimization

The optimization of maintenance actions is an area of multiple criteria decision making and need involving more than one objective function to be optimized simultaneously. The reliability performance, life cycle cost, environmental impact and social performance should be considered simultaneously. The decision also should be made from setting product characteristics to providing information for customers. Hence the basic framework for optimization should be based on Figure 69. The elements of this framework including four areas have been explained in details in the next section. Moreover, we need a framework for optimization which provides a reliable way with which to compare different decisions/engineering designs. The solutions are difficult to find when the problem is large and, or are very nonlinear, have many components, or are expensive to compute [19]. In these cases, the hierarchical optimization is a proper way to tackle these problems. Hence we also proposed a hierarchical optimization framework for optimization of engine maintenance (Figure 70).

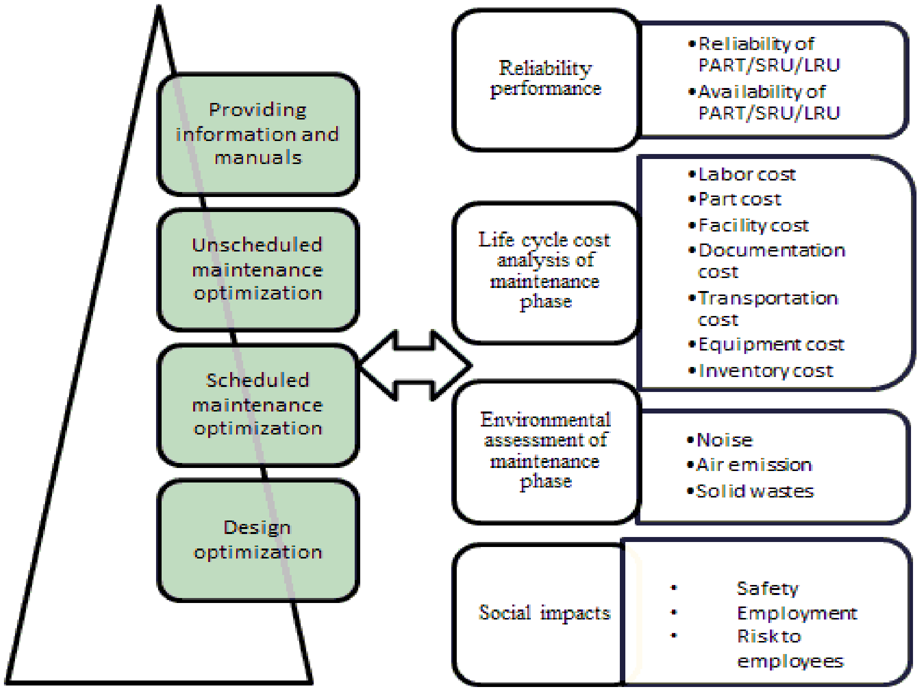


Figure 69 : Optimization framework for engine maintenance

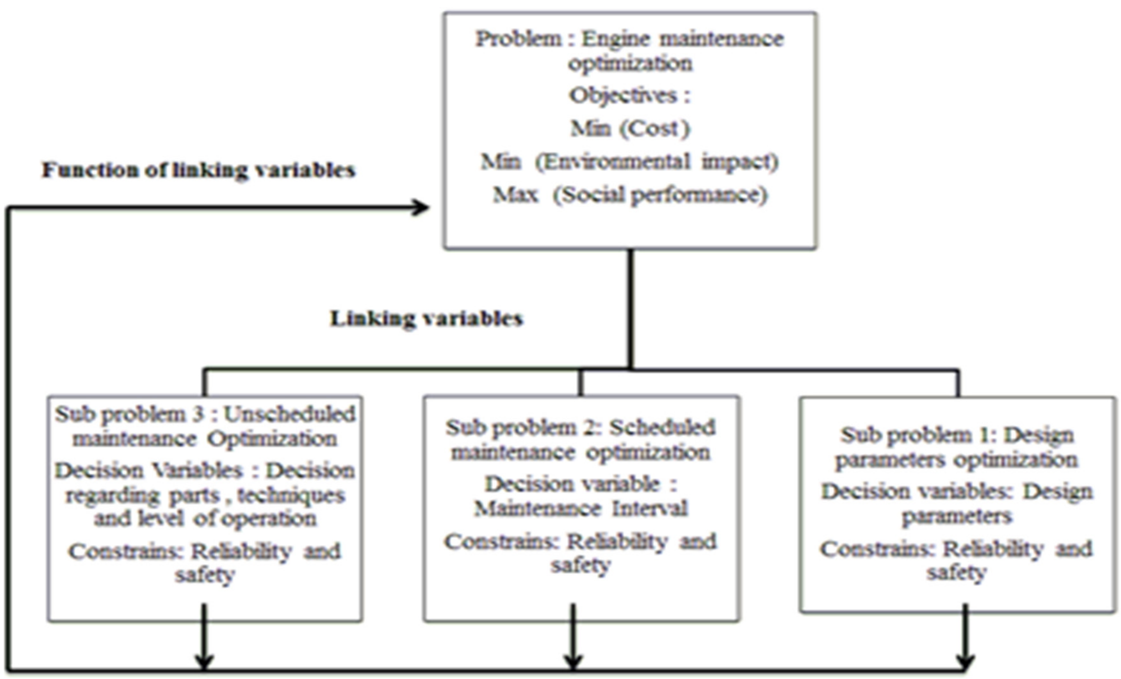


Figure 70 : Hierarchal framework for optimization

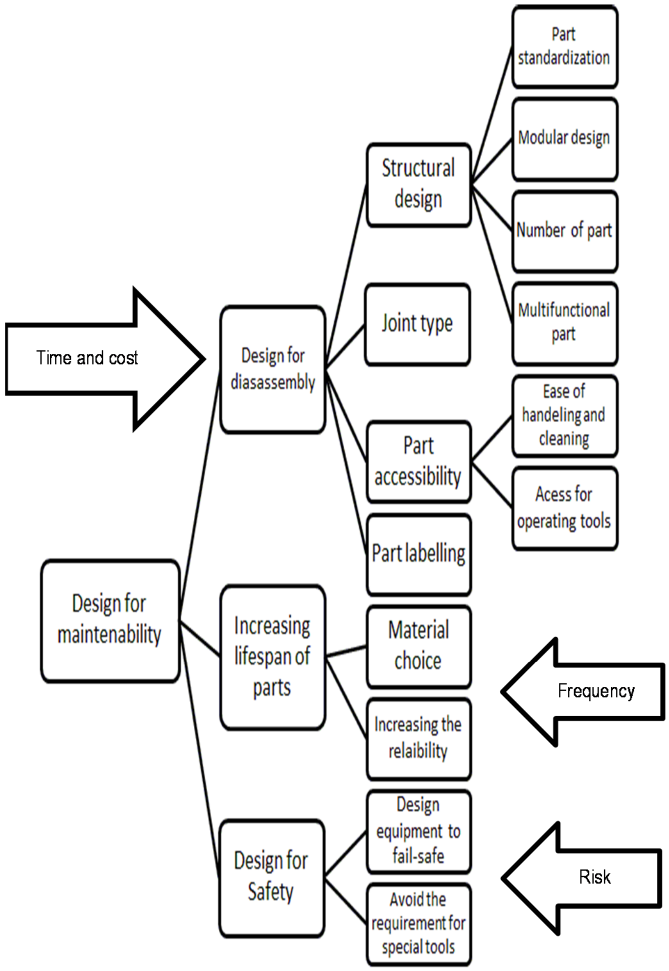


Figure 71 : Design for maintainability for aircraft

4.4.5.3. Design optimization

Maintainability is the degree to which a product allows safe, quick and easy replacement of its component parts. It is embodied in the design of the product. Figure 71 shows the potential areas of design for maintainability. At the conceptual design stage, optimizing future aircraft considering environmental and operating performance needs an integrated approach that identifies the multidisciplinary nature of aircrafts, and can take into account simultaneously variables and constraints from related disciplines [20]. In the case of optimization of engine maintenance, we need to identify the design for maintainability parameters, the associated cost performance, risk, reliability and environmental performance. With knowing the current parameters and improvement options considering these disciplines, we can develop the optimization model.

4.4.5.4. Scheduled maintenance optimization

There are several studies which address the optimization of maintenance interval. For example, work done in [21] proposes a periodic preventive maintenance of a system with deteriorated components. Two activities, simple preventive maintenance and preventive replacement, are simultaneously considered to arrange the preventive maintenance schedule of a system. Regarding the engine maintenance, we need to consider the scheduled maintenance tasks related to each part and identify the cost performance, environmental impact, reliability and risk of these tasks.

4.4.5.5. Un-Scheduled maintenance optimization

The optimization of un-scheduled maintenance should be done regarding reparable items and non-repairable items. Work done in [18], defined three decisions regarding parts; replacing, repairing or discarding. Moreover the authors addressed the level of operations. In addition, using special techniques can lead to increasing the part life span and reducing the parts scrap rate [17]. Therefore, with integration of these essential decisions, we can develop a holistic optimization.

4.4.5.6. Providing information and manuals

The required information which can be provided by manufacturers include disassembly and recycling information such as material composition, hazardous material type, and design for disassembly level, recycling category and disposal consideration such as related regulation. For the procedure, related directives for each task, best practices and check list can also be considered. In order to have a manual demonstrating an effective and practical means of preventing or limiting harmful impacts to the environment during maintenance activities, reviewing literature can bring some insights. In this part, we reviewed some related works. The first study is a guideline for the Vehicle Dismantling and Recycling, this guideline was prepared by Ministry of Environment of Canada /Environmental Protection Division, in order to assist vehicle dismantlers and recyclers in meeting the requirements of the regulation [22]. All regulation related to waste management of Ozone depleting substances and other halocarbons; Oils, brake fluids, solvents, fuels and other hydrocarbons; Antifreeze; Lead and lead-acid batteries; Waste tires; Mercury switches; and Windshield washer fluids have been addressed in this document. In each category, the legal requirement, operational checklist and best practices with respect to dismantling, storage, transportation and recycling have been explained in this document. The second study is Environmental best practices for highway maintenance Activities which has been prepared by Ministry of transportation and infrastructure of Canada (MoT) [23]. The MoT, contracts the maintenance of British Columbia's provincial highways to privatized Road and Bridge Maintenance Contractors. These contractors play an essential role in meeting the Ministry's mandate to provide safe transportation, and to carry out all works in an environmentally responsible manner. The Ministry has developed this manual of Environmental Best Management Practices for Highway Maintenance Activities. These standardized practices and protocols are designed to be applicable across the province, and to serve as a practical and cost effective means for contractors to meet regulatory agency requirements, and public expectations for environmental protection. In this document, sixteen environmental best practices have been developed for 9 maintenance categories, and covering 35 specific maintenance activities. This document is organized into three main segments: key environmental concerns, legislative requirements and performance standards and environmental best practices. Therefore, an appropriate maintenance manual with objectives addressing environmental concerns, addressing environmental impact of maintenance activities, addressing the relevant policy and regulation requirement and standards (provincial, federal , etc.) applicable to maintenance activities, addressing the relevant best practices , can be provided by manufacturers to preventing or limiting harmful impacts to the environment during maintenance activities.

4.4.5.7. Challenges

Considering of the highest reliability and safety requirements as well as high uncertainty, there is a little scope for optimizing maintenance outside the manufacturer [13]. In order to have a multi-objective optimization, it is needed to have detailed information about the LCA and LCC. As the maintenance phase occurs in the scope of operation, access to this level of information is difficult or sometime impossible. For example the main issue in order to calculate the impact of part replacement during maintenance operations is the way to estimate the frequency of failure rate of the components and sub-parts. It is a challenging issue due to the different approaches and considering the probabilistic nature of the failure rate of components. Overhaul and shop operations are other concerns because these activities are included in restoration task, but the detailed information regarding these activities is not available. Therefore integrated optimization should be done with collaboration of all parties. Resolving a distributed decision making framework with collaboration of key players is a challenging task which needs to be addressed in an organized way.

4.4.6. Conclusion

There is a growing demand as well as interest for considering social and environmental impacts of product during the life cycle. Therefore, manufacturers need to have a sustainable approach to optimize products characteristics at the design stage. Aeroplanes are amongst the most expensive industrial systems which at the same time have the highest reliability and safety requirements. The aerospace industry, with complex and expensive products and need for high requirements of safety and reliability, face more challenges in order to have a sustainable approach at the design stage. The maintenance operation is an essential phase in the life cycle of aircraft considering the environmental impacts and costs of operations. In this paper, we proposed a framework for optimization of aircraft maintenance in a framework of sustainable development. Working on a detailed case study can be proposed as future research.

References

[1] R. Morimoto, V. Agouridas," Supporting Aircraft Manufacturers to Formulate and Implement Sustainable Development Strategies Systematically," Journal of the Transportation Research Board., No. 2106, 2009, pp. 12–19.

[2] R. Handfield, et al. "Integrating Environmental Concerns into the Design Process: The Gap between Theory and Practice" IEEE Transactions on Engineering Management, 2001, VOL. 48, NO. 2

[3] M.D. Bovea, V. Pérez-Belis," A taxonomy of ecodesign tools for integrating environmental requirements into the product design process", Journal of Cleaner Production 20.1 2012: 61-71.

[4] D. Wheeler, B. Colbert, and R. E. Freeman, "Focusing on value: Reconciling corporate social responsibility, sustainability and a stakeholder approach in a network world." Journal of General Management 28.3 2003: 1-28.

[5] J. Fiksel, "Design for environment: creating eco-efficient products and processes", McGraw-Hill, 1996, USA

[6] F. S. Nowlan, H. F. Heap, "Reliability-centered maintenance. UNITED AIR LINES INC SAN FRANCISCO CA,1978

[7] H. Kinnison, , "Aviation Maintennace management", 2004 Mc Graw Hill

[8] http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/airtrans.pdf

[9] M.V. Chester, "Life-cycle Environmental Inventory of Passenger Transportation in the United States". UC Berkeley: Institute of Transportation Studies, 2008. Retrieved from: http://escholarship.org/uc/item/7n29n303

[10] F. Nermy et al., "Environmental Improvement of Passenger Cars (IMPRO-car)", JRC-European Comission, 2008.

[11] Ford Product sustainability index/ Available at http://corporate.ford.com/doc/sr11-ford-psi.pdf

[12] MA. Weiss et al., "On The Road In 2020, A life-cycle analysis of new automobile technologies", Energy Laboratory Report # MIT EL 00-003, Energy Laboratory Report, 2000

[13] R. Dekker, & P. A. Scarf, (1998) "On the impact of optimisation models in maintenance decision making: the state of the art" Reliability Engineering & System Safety, 60(2), 111-119.

[14] Gray, D.A., Airworthy (1992)" Decision support for aircraft overhaul maintenance planning. OR/MS Today, December, pp. 24-29.

[15] MC. Dijkstra, et al.," Planning the size and organization of KLM's aircraft maintenance personnel", Interfaces, 1994, 24(6), 47-65.

[16] C.F.H. Van Rijn et al. "A maintenance manning assessment tool,"In Proceedings 3rd. EsReDa seminar on Equipment Ageing and Maintenance, Chamonix, France, 1992.

[17] Y. O. S. H. I. H. I. K. Tanaka et al. "Large engine maintenance technique to support flight operation for commercial airlines." Mitsubishi Heavy Industries Technical Review 40.2, 2003: 5

[18] H. Saranga, U. D. Kumar, "Optimization of aircraft maintenance/support infrastructure using genetic algorithms—level of repair analysis". Annals of Operations Research, 2006. 143(1), 91-106.

[19] Nelson Sigurd, " Design Laboratory Distributed Design and Hierarchical Optimization ",Distributed Design and Hierarchical NLP,ARC Conference, 1997,Ann Arbor MI, June 3 & 4,

[20] N. E. Antoine, I. M. Kroo, Aircraft optimization for minimal environmental impact. Journal of aircraft, 2004. 41(4), 790-797.

[21] Y. T. Tsai et al. "Optimizing preventive maintenance for mechanical components using genetic algorithms". Reliability engineering & system safety, 2001. 74(1), 89-97.

[22] Guideline for the Vehicle Dismantling and Recycling (Ministry of Environment of Canada /Environmental Protection Division) retrieved from: http://www.env.gov.bc.ca/epd/industrial/regs/vehicle/pdf/guidebook_vehicle_reg.pdf

[23] Environmental best practices for highway maintenance Activities (Ministry of transportation and infrastructure of Canada) retrieved from: http://www.th.gov.bc.ca/publications/eng_publications/environment/references/Best_Practices/Envir_Best_Practices_Manual_Complete.pdf

[24] J.V.O., Fernandes Lopes, "Life Cycle Assessment of the Airbus A330-200 Aircraft", Master thesis, 2010, retrieved from : https://dspace.ist.utl.pt/bitstream/2295/792342/1/Tese_JoaoVascoLopes.pdf

[25] S., Keivanpour, D., Ait Kadi, and C., Mascle, "Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network," SAE Int. J. Mater. Manf. 2014,7(1):

5. Chapter Five

An integrated approach to Value chain analysis in the context of sustainable development

This chapter is dedicated to the following articles:

“A Conceptual Framework for Value Chain Analysis of Aircraft Recycling in the Context of Sustainable Development”, has been published as technical paper of SAE 2014

"End-of-Life Aircraft treatment in the context of Sustainable Development, Lean Management and Global Business (Part A: Integrated framework for strategic optimization)”, has been submitted to the Journal of Industrial Ecology

"End-of-Life Aircraft treatment in the context of Sustainable Development, Lean Management and Global Business (Part B: Optimization model, solution approach and application perspective)”, has been submitted to the Journal of Industrial Ecology

The titles, figures and mathematical formulations have been revised to the keep the consistency through the thesis.

5.1. A conceptual framework for value chain analysis of Aircraft treatment in the context of sustainable development

5.1.1. Résumé

La fin de la phase de vie d'un avion est une phase relativement complexe du cycle de vie de ce produit. En effet, lorsque les avions sont retirés du circuit de transport elles sont stationnés dans des conditions particulières. Lors du recyclage de ces avions, les éléments importants sont démontés et le reste démantelé. Les matériaux sont séparés et recyclés, les déchets brûlés ou abandonnés et les matières toxiques retenus ou incinérés. Toutes ces activités doivent être effectuées de manière écologiquement responsable et la valeur ajoutée ainsi créée collectivement doit être prise en considération. Ce document vise à fournir un cadre conceptuel pour l'analyse de la chaîne de valeur des processus de recyclage des avions dans le contexte du développement durable. La chaîne de valeur liée au recyclage des avions en fin de vie a été choisie pour produire une analyse en profondeur de la chaîne de valeur, en tenant compte des préoccupations environnementales et socio-économiques. Dans ce travail, nous avons clairement identifié cette chaîne de valeur ainsi que les impacts environnementaux et sociaux. En plus, à cela, nous avons pu déterminer le processus de prise de décision le long de la chaîne de valeur et du cadre politique, y compris les codes, règlements et normes. Enfin, nous avons proposé sur la base de l'analyse de la chaîne de valeur, les recommandations pour l'efficacité, l'efficience et la stabilité dans la chaîne de valeur.

Mots-clés: Avions en fin de vie (EOL), analyse de la chaîne de valeur, développement durable

5.1.2. Abstract

The End of Life phase of Aircraft is a relatively complex phase in life cycle of this product. The retired Aircrafts need to be parked in a certain conditions. The valuable parts are disassembled and the rest of them are dismantled. Materials are separated and upgraded, waste is burned or deserted and toxic materials restrained or incinerated. All of these activities should be performed in an ecologically right manner; however, collectively produced added values for all stakeholders need to be considered. This paper aims to provide a conceptual framework for value chain analysis of Aircraft recycling process in the context of sustainable development. The value chain related to recycling aircraft at the end of life was chosen to generate an in-depth analysis of a value chain, considering environmental and socio-economic concerns. The value chain framework for recycling of fleet is identified. The key processes with environmental and social impacts are determined. The decision making process along the value chain and the policy framework including codes, regulations and standards are addressed. Finally, based on the value chain analysis, the recommendations for effectiveness, efficiency and stability across the value chain are proposed.

Keywords: Aircraft at the End of life (EOL), value chain analysis, sustainable development

5.1.3. Introduction

The Aircraft Fleet Recycling Association (AFRA) estimates that more than 12,000 aircrafts will be retired in the next two decades [1]. Recycling and disposal of these aircrafts can provide environmental, social and economic values. The EOL phase of Aircraft is a complex phase in life cycle of this product. The retired Aircrafts need to be parked in certain conditions. The valuable parts are disassembled and the rest of them are dismantled. Materials are separated and upgraded, waste is burned or deserted and toxic materials restrained or incinerated. All of these activities should be performed considering environmental concerns and may lead to added value for the actors in the business loop. In this paper, the EOL aircraft recycling process is analyzed as a value chain and address the different aspects of this problem in the sustainable development context. The research field related to EOL aircraft recycling is completely new and there is not a substantial amount of literature that already exists. The authors in [2] addressed the topic of value extraction from EOL aircrafts. The authors tried to answer five important questions about the recycling of the aircrafts: why, when, what, who and where. They focused on the process of EOL aircraft recycling, the components as well as its economics. The authors in [3] provided an assessment of life cycle engineering in preliminary aircraft design. They proposed an interdisciplinary approach in order to integrate the sustainability issues in aircraft design stage. With respect to the recycling and disposal phase, they considered the “Ladder of Lansink” approach to the aircraft dismantling which already proposed in [2]. In this approach, the first choice from environmental point of view is using the aircraft parts in other aircraft which still being operated. If reusing is not applied, the recycling or down-cycling (which refers to chemically combined or physically joined parts) is the choice. If these options cannot be done due to technological restriction then energy recovery by burning can be the solution. Finally, in the event that none of these options are available, landfilling is the last option. Another study in end of life aircraft literature [4] is related to evaluation of different strategies for dismantling of skeleton of the aircraft. This work examined the difficulty of recycling of the skeleton due to use of mix materials. The author believes that recycling the skeleton is not a process with very high added value, such as parts reselling, though smart sorting can increase the extracted value from this operation. The authors in [5] proposed a mathematical model in order to optimize the effectiveness of the aircraft dismantling process. This research studied which parts must be sorted before shredding and which units need to be shredded directly. The author in [6] developed a decision tool in order to maximize the profit of dismantling process with respect to the sorting stages. This work considered different scenarios for dismantling and introduced a mathematical model in order to show that which scenario can be chosen depending on available time, costs and revenues related to the scenarios. The synthesis in recent literature reveals that there is not an integrated approach to EOL aircraft recycling in sustainability framework. Hence, this article covers this gap in literature and introduces a novel approach in order to analyze the different aspects of the EOL aircraft problems in the context of sustainable development, as well as value creation for the players involved in the problem. The rest of the paper is organized as follows: next section addresses the background of the problem including sustainability in aviation industry, EOL aircraft recycling issues, manufacturer responsibilities and value creation in sustainability context. After this part, the proposed framework and its theoretical basis are introduced. Next section demonstrates the application of this framework to the recycling of the EOL aircrafts and finally, we conclude with some remarks and outlines for future research.

5.1.4. Background

It is useful to consider the sustainability paradigm in aviation industry and some details regarding the EOL aircrafts and the value creation framework in the operation of EOL aircraft recycling. This section will reflect some of preliminary concepts related to the topics and the relevant elements.

5.1.4.1. The sustainability paradigm in Aviation industry

Aviation provides social and economic benefits for society and global economy [7]. These benefits are not only providing transportation services for passengers around the world but also supporting over 56.6 million jobs across the globe and the role in the global economy [8]. Hence, the first concentration of aviation is meeting the society needs for transportation and sustaining a relationship with stakeholders. Minimization of greenhouse gas emission and prevention of dangerous interference with climate system is another objective of a sustainable aviation. However, in 2011, aviation contributed around 2% of global CO2 emission [9] but the aircraft manufactures are working on reducing the emission and also improving the quality of air through innovative technologies [8]. Another environmental impact of the aviation industry is noise. Noise has become a main constriction to air traffic, 60% of all airports considering it as a major problem and the nation's fifty largest airports inspecting it as their principal issue [10]. Therefore, limiting and reducing the impacts of aircraft noise is a concern for commercial aviation. Reducing environmental footprint and efficient use of natural resources push manufacturers to have a life cycle approach from design to end of life phase. In this approach, each step of manufacturing process and supply chain as well as aircraft at the end of life is a part of manufacture's environmental responsibility [8].

The authors in [11] report a survey of common practices in aerospace manufacturing industry regarding sustainability. According to this study, the major practices could be divided into two categories: manufacturing practices and facility practices. Manufacturing practices are included product modification and improvement in addition to process modification and improvement, where modification means changing in current products and processes in order to be more sustainable and improvement means making alteration in products or processes in order to be more efficient and leaner. The author divided the facility practices in two groups: regulatory and general. Regulatory refers to mandatory legal codes as well as non-mandatory standards or certifications for lean, sustainable development and environmentally benevolent and finally general practices includes recycling initiatives, environmental awareness workshops or those public activities aligned with environmental stewardship. This research concludes with potential gaps in these practices and highlights that, target environmental efforts appears to be material working and surface finishing with respect to the high energy consumed and chemical waste. However, the component and assembly, re-using, remanufacturing are those practices that seem lack of attention paid to them. Another gap is related to the lack of standards or universal metrics for assessing environmental impacts, so the measurement of value and improvement are not clear and finally, the significant lack in regulatory framework, which made the efforts promotional. Synthesis in literature related sustainability of aviation industry shows that there are several challenges with respect to the aircraft recycling which should be addressed in future researches including responsibility of manufacturers, the effective feedbacks for design stage, the different actors in recycling chain, the challenges of re-using and remanufacturing as well as the reverse logistic challenges for aircraft manufacturers.

5.1.4.2. Aircraft at the End of life

Leaving the aircrafts near airports and in desert areas is a common practice in the aviation industry. These abandonments represent a potential significant environmental damage, encourage uncontrolled aircraft dismantling and promote the introduction of parts in the aviation through a black market. In the coming years considering the expected increase in retirements of fleet, aviation industry faces a new problem. The rising cost of fuel must also be taken into account, since this factor could force the owners to withdraw aircrafts from services because they are unable financially to support the operating of aircraft with intensive fuel consumption. Fortunately, aircraft owners (rental companies, airlines, banks, part brokers, individuals) are increasingly environmentally conscious. The green image associated with treatment of aircrafts at the end of life based on environmental concerns moved gradually as a criterion of competitiveness on the global market [6]. According to the author in [4], at this time, the aircraft is withdrawn from service before the end of its operational life in order to reduce operating costs and the replacing it with a more efficient aircraft. Aircraft recycling at end of life can be considered as a significant financial windfall. Indeed, it is possible to generate more than tens of thousands of U.S. dollars, considering only the recycling of materials, regardless of the resale of the reusable parts from aircraft. In addition, green considerations are becoming more important at all levels of the life cycle of products. In this context, the reduction of the environmental impact of a retired fleet through recycling process has an important role for all actors in operation processes of recycling the EOL aircrafts. Moreover, such approach can ensure a long term social benefits. Indeed, the development of this sector and having an infrastructure for recycling can lead many lasting jobs opportunities, which are a factor of social and local development. According to authors in [14], products with different characteristics experience distinct end-of-life strategies. Now, end-of-life treatment systems are developed by industry volunteers or as a reaction to legislation. Though, solutions to this complex subject must incorporate both technical and business features [13].

Many industries are involved and have already moved in this direction, including automotive and consumer electronics. However, there are some major differences in treatment of the case of EOL aircraft. The volume of EOL aircrafts is very small compared to the volumes of electronics or EOL vehicles. In addition, the residual value of components and materials in aircraft can be very high, depending on the technology of dismantling and disassembly used; aircraft consisting of high quality alloys and spare substantial market value, as engines and landing gear [13]. Moreover, according to estimations from Airbus and Boeing between 6000 and 8000 commercial aircraft will be retired in the next 20 years. The treatment of these aircraft must be economically attractive to produce a value for all actors and thus needs advanced methods and processes.

5.1.4.3. Manufacturer's responsibility

According to authors in [13] "Aerospace original manufacturers have a long history of looking for ways to reuse or recycle aircraft and their components. In the past, at least 50 percent of the material used in aircraft construction was reused or recovered. The two largest airframe manufacturers, Airbus and Boeing, are at the head of research and main projects in this field ". Airbus initiated a PAMELA project with recycling and recovery rate by 85 percent of the aircraft weight [14]. Boeing has taken a leadership role in aircraft life cycle and end-of-service recycling strategies for more than 50 years. Aircraft Fleet Recycling Association, AFRA, is a global consortium of more than 40 companies that provide environmentally responsible options for aging aircraft. These options include maintaining and reselling reliable airplanes and returning them to service. Safe parts recovery scrapping and recycling services are available for airplanes that cannot be returned to service [15]. Bombardier is also working on recycling challenges. In 2012, this company continued its partnership with the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ), as well as the other research centers and universities to better understand end-of-life requirements and commercially practical recycling technologies for aircraft [18]. In life cycle approach, environmental product declaration (EPD) is a standardized technique of calculating the environmental impact of a product or system. This document includes information on the environmental impact of raw material acquisition, energy use and efficiency, materials and hazardous substances, emissions to air, soil and water and waste generation ([16], [17]). For example, Bombardier in order to ensure transparent communication is going to publish (EPDs) for Aircrafts with complete transparency by applying associated ISO standards and external verification schemes [18]. However, in the absence of rules and regulations for EOL aircrafts, these efforts and practices are done in the promotional framework for companies green images while the detailed information of environmental impacts of product during EOL phase for vehicles reflected in EPDs (see. for example, EPD of the SPACIUM train of Bombardier [19] and Volvo FH12 [20]).

5.1.4.4. Value creation in sustainability context

Value creation is a topic in the field of strategic management which received a lot of attention in individual and group level as well as organization and society level ([21]; [22], cited in [23]). According to [24], [25], value creation activities and processes must be understood based on the firm's essential relationships with its stakeholders. The stakeholder view theorizes the capacity of the firm to make sustainable value over time and therefore long term value can be defined based on the relationship of the firms with their stakeholders [25]. Based on this concept, the authors in [23] introduce a conceptual framework for firm's value creation. In this framework, stakeholders capabilities defined as "the stakeholders effective opportunities to undertake actions and activities with the firm that they want to choose to engage in the value creation process" ([23], p.6). We defined the value creation process of EOL aircraft recycling process based on this framework. Figure 72 illustrates the mechanism for value creation in sustainability context. The drivers of the sustainability are included the regulation, stakeholders, image and competition in aviation industry. The outcomes are comprised growth, innovation as the result of novel technologies and processes, cost effectiveness and reputation. Hence, the outcomes extracted from different sub-processes of recycling produces value for actors in the business loop. The value added process can lead to actor's satisfaction and this satisfaction is the source of the actions and activities that re-generate the value in the process.

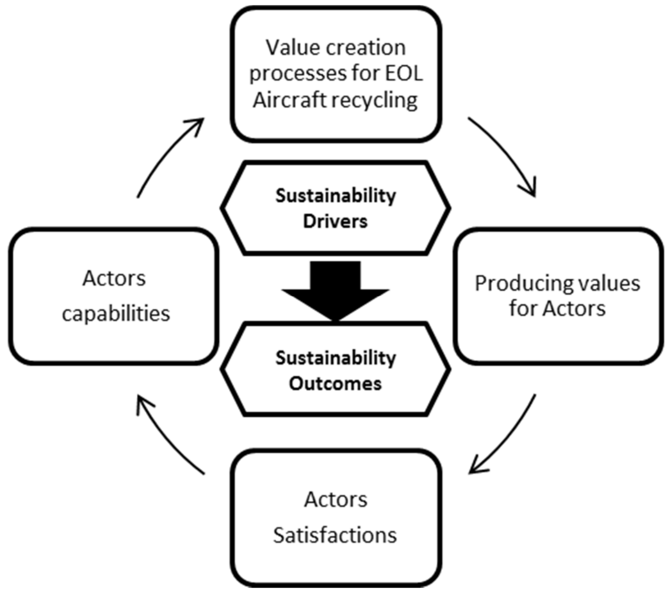


Figure 72 : The value creation process in EOL aircraft recycling considering actors role

The authors in [26] developed a sustainable-value framework that links the challenges of global sustainability to the creation of shareholder value by the enterprise. The author in this work demonstrated that how the global challenges related to sustainable development, can be observed through the appropriate set of business lenses and aid to recognize strategies and practices that contribute to a more sustainable context while at the same time can drive shareholder value. In their framework there are two axes. “The vertical axis reveals the need of firm to manage today’s business and at the same time create tomorrow’s technology and markets. The horizontal axis shows the need of firm to grow and keep internal organizational skills and competences and simultaneously pervading the firm with new views and knowledge from the external” ([26], p.57). As the result of this division, the framework has four parts and in each part there is a strategy and corporate pay-off for stakeholders: Pollution Prevention (Cost & Risk Reduction); Product Stewardship (Reputation & Legitimacy); Clean Technology (Innovation & Repositioning); and Sustainability Vision (Growth Trajectory). Based on this framework, we proposed a novel basis for driving sustainable value in EOL aircraft recycling chain of actors (Figure 73). For each section the drivers are identified as well as strategy and pay-off for actors involved in the problem.

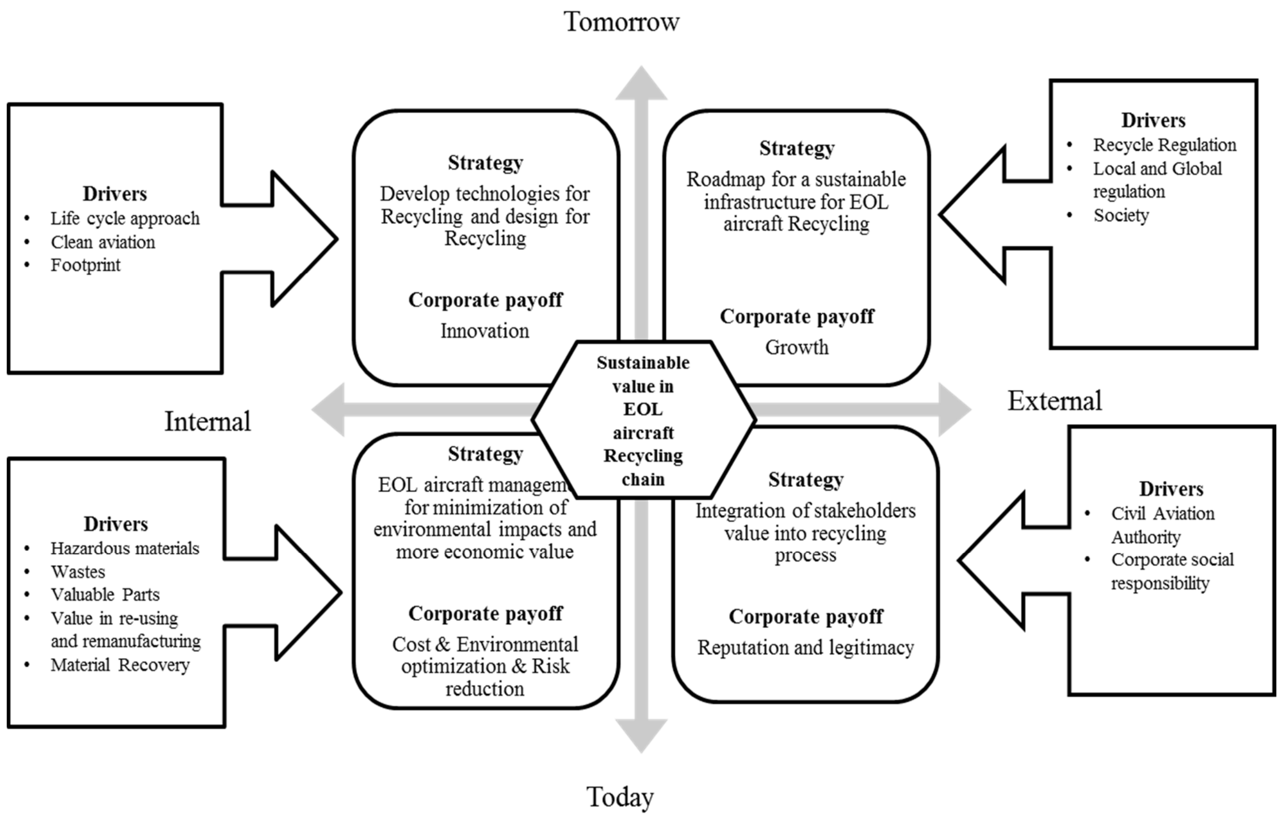


Figure 73 : Driving sustainable value from EOL aircraft recycling chain

5.1.5. Sustainable value chain

The research field related to green supply chain and value chain are rapidly developing. Although the research field is new, a considerable amount of literature now exists. Here, we provide some review of the recent literature in this regard. The authors in [27] provided a systematic literature review related to value chain methodologies considering globalization and ecological performance. According to this study, the methods for evaluating harmful impacts of value chain highly required in recent years. These methods are included Substance Flow Analysis, Life Cycle Assessment and Energy Flow Analysis. This study emphasizes that the definition and system boundaries for integration of environmental thinking to the value chain is important because it can lower the costs of data collection and analysis but at the same time may affect the results adversely due to truncation error. Hence, it is essential to decide about the system boundaries. The role of green value chain in creating sustainable completive advantages for manufacturing in Malaysia studied in [28]. The authors in this study believe that in today's business environment, manufacturers need to shift their paradigm from the "conventional departmental time-static worldview" to a new "holistic perspective" that can efficiently allow the interconnection between economic growth, environmental and social responsibility ([28], p.1). A methodology of value chain analysis for material flow analysis of the UK iron and steel sector with a consideration of the economic and environmental dimensions is presented in [29]. The authors in [29] believe that "value chain analysis is a robust methodology for exploring various aspects of the economy–environment interface, and a useful complement to material flow or life cycle analyses with a potentially very widespread applicability. The value chain analysis also provides a framework for coherent and integrated responses by industry as well as policy-makers, through its focus on linkages within different stages and actors in a chain and on the potential for systemic efficiencies" ([29], p.507). The authors in [30] studied the environmental management of value chains and demonstrate the network dynamics of value chain considering stakeholders and life cycle approach via the case of Finnish metal industry network. The application of Environmental Value Chain Analysis to product's take-back systems is introduced in [31]. The analysis studies the information, money and product flows between players. The players of concern are including the producers, government, consumers and recyclers. Regardless of taking into account the environmental aspect in value chain analysis, there is not a holistic approach for analysis the value chain in the sustainable development context. However, the models, methods and approaches in supply chain analysis can be utilized for concept development.

5.1.5.1. Theoretical basis

An analytic framework for assessing ecological impacts of commodity supply chains and appropriate policy responses is proposed in [32]. The authors introduced seven steps for this framework. The first step is defining the framework of the supply chain. The second step is identifying trade flows, supply and demand. Third and fourth steps can be performed with assessing the environmental and social impacts of supply chain. The fifth step is identifying national and international policy and then evaluation of power relationship along the supply chain and finally policy analysis of the supply chain. Based on this framework and four categories of theories (Figure 74), we proposed an integrated framework for value chain analysis in the sustainable development context. Before explaining the conceptual framework, the theoretical basis for developing the concept of value chain with sustainability consideration is discussed in this part.

Porter developed the concept of the value chain in the context of competitive advantage [33]. He developed this concept in order to analyze which particular activities may create value for companies. But, Porter's value chain approach is limited to the firm level and ignoring the analysis of the activities outside the company. The global commodity chain concept is developed in [34]. This framework has four main elements: input-output structure, regional/international structure, institutional and governance framework. The Gereffi's framework also covers institutional mechanisms and inter-firm relationships. There is not an independent ecological concept for value chains until now [35]. Though, the integration of the environmental thinking into value chain has led to developing some new concepts like green value chain or eco-friendly value chain. Hence, there is a need to develop a holistic approach to value chain analysis which covers value added activities, governance and inter-firm relationship, regional or international dimension as well as sustainability objectives. According to authors in [36], The Triple Bottom Line approach evaluates the impact of an organization's activities on profitability, shareholder value and its social, human, and environmental assets. Regarding three dimensions, there are some specific criteria. For example, for economic aspect, sales, profit and monetary flow, for environmental aspect, air quality, energy consumption and waste production and finally for social aspect, labor issues, community impacts can be considered as the criteria for evaluation of the impacts of the organization's activities. Based on [37], the performance measurement has defined as "the process of quantifying the efficiency and effectiveness of past actions". In addition, it can be defined as "explains it as "the process of evaluating how well organisations are managed and the value they deliver for customers and other stakeholders" [38].

Hence, performance measurement provides a tool for evaluating not only the efficiency or effectiveness of a process but also the value delivered to all stakeholders through the operations.

Stakeholder theory emphasizes that companies need to consider the effect of their actions on the group of the stakeholders. Not only suppliers as the main stakeholder in implementation of green supply chain, but also the other internal and external stakeholders need to be identified and the impact of manufacturer's strategies on them need to be assessed [13],[39]. The other theory, resource dependence theory proposes that in the supply chain, member firms should depend and cooperate to find higher performance advantages in the long-run instead of pursuing short-term benefits at the expense of others [40].

5.1.5.2. Conceptual framework

We used this theoretical basis in order to develop a conceptual framework for value chain analysis in the context of sustainable development (Figure 74). The framework has four general steps and some sub-steps in each one. The first step starts with definition of the service or product and its value chain. The geographical boundary of the value chain and the problem context including market and industrial trends, the effect of technological development and external factors which affect the value chain need to be defined. The second step is identifying the particular activities with essential social and environmental impacts. Hence, in this step the exchange flows through the value chain based on the triple bottom line theories need to be mapped. This step allows the sustainability analysis of the value chain. The third step of the framework includes identification of the players and inter-relationships. This step provides insights regarding the policy and decision making process. And finally, the last step is performance measurement including the cost efficiency of the value chain, evaluation of the meeting the environmental and social objectives, the stability of the network of the players and policy consistency over the chain.

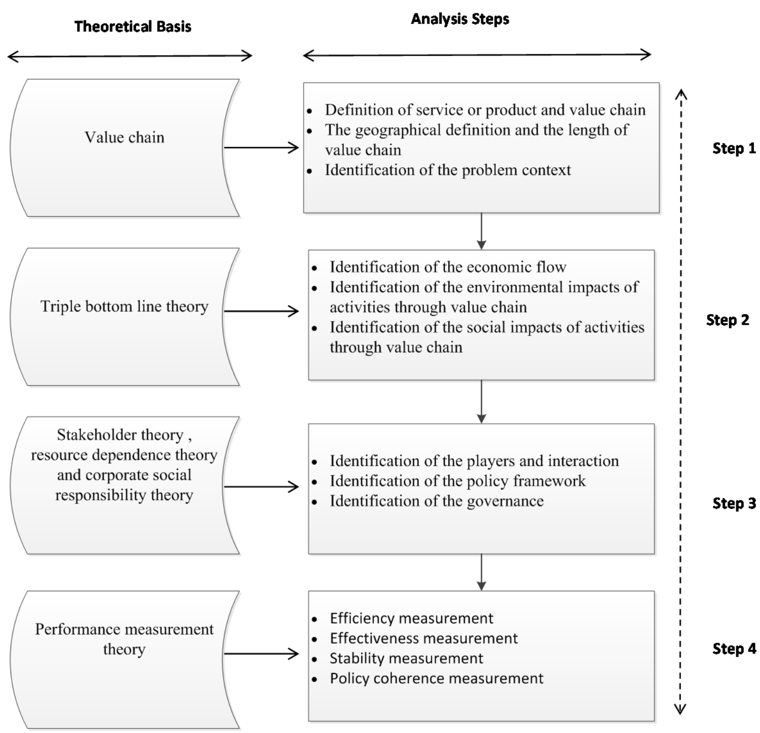


Figure 74 : The conceptual framework for value chain analysis in the context of sustainable development

5.1.6. Application in Aircraft Recycling

This section explains the details regarding the application of the proposed model in the case of value chain analysis of the EOL aircraft recycling in the context of sustainable development. We defined four steps and in each step we demonstrate the details and guideline of the application of the framework.

5.1.6.1. Step 1: Value chain framework & problem context

This step goes into more details about the EOL aircraft and its value chain. We demonstrate that which information is needed, what is the value chain of the recycling, the length of value chain and external factors which need to be considered.

5.1.6.1.1. Definition of service and value chain of recycling

Before introducing the value chain of recycling, knowing some information about the target EOL aircrafts is crucial. This information provides awareness about the decision of operators for dismantling, the time for scrapping, the interests and motivation for dismantling and back-up information for understanding the economics of EOL aircraft and essential environmental and social challenges. Table 24 provides a list of useful information which needs to be gathered and analyzed. This list extracted from the EOL aircraft literature.

Table 24 : The useful information related to EOL recycling value chain

NO	Information	The value of information
1	Aircraft type/Range /Engine	Estimation of Recyclability and recovery rate , The economics of valuable parts
2	Previous /current and next generation	Prediction of the Number of the aircrafts at the EOL
3	The amount can be scraped	Estimation of Recyclability and recovery rate
4	Materials in structure	The material recovery channels ,dismantling and environmental challenges
5	Maintenance manual	Disassembling information
6	Maintenance costs	The motivation of the owners and operators for Dismantling
7	History of recycling (age, cycle, hours)	The lesson learnt of operations
8	Operators	The decision of operators for dismantling, the types of the aircraft in the service
9	Spare parts demand	Estimation of the valuable parts sales
10	Number of Current/stored/parked/scrapped	Prediction of the Number of the aircrafts at the EOL
11	Influence of legislation	The impact on the retirement of the aircrafts and phasing out
12	Usage (freighter or passenger)	The age of dismantling

The global trends and forecast also play an important role. For example, Current Market Outlook (CMO), Airbus a Global Market Forecast (GMF) and Avitas a Global Outlook for Air Transportation (GOAT) are some of main forecasts in aviation industry. The market for the components and the amount of aircraft to be scrapped, the effect of technological development on expected life time and role of stakeholders are the other factors which makes the problem context of the EOL aircraft business. According to [13] the role of component dealers, the demand for spare part component as well as the external factors include financial crisis, demand for used aircraft especially in India, Middle East, Eastern Europe, and especially Russia, are the others elements which impact the economics of this value chain.
The first step of a value chain analysis is the mapping of the value chain [35]. We need to define the boundary of the value chain of recycling, the actors involved in the problem and then to 'map' the traced flows of materials. Based on [35] a mapped value chain includes "the actors, their relationships, and economic activities at each stage with the related physical and monetary flows".
According to [13] the process of recycling of the EOL aircrafts entails of several steps. Several essential components can be retained before dismantling, recycling or disposal. Engines, landing gears, avionics, and electronic motors are the most valuable parts which may be reused. These parts need recertifying process in order to be able to enter to the second hand part market. Doors, wings, interiors can be used for training purpose. Recycling the material is the other aspect of end of life solutions. Four major classes of materials ranging from low cost interior materials to high performance alloys and composites used in aircraft construction. And finally the waste stream will send to the waste treatment facility for energy recovery or disposal. The value chain of the EOL aircraft recycling is shown in Figure 75.

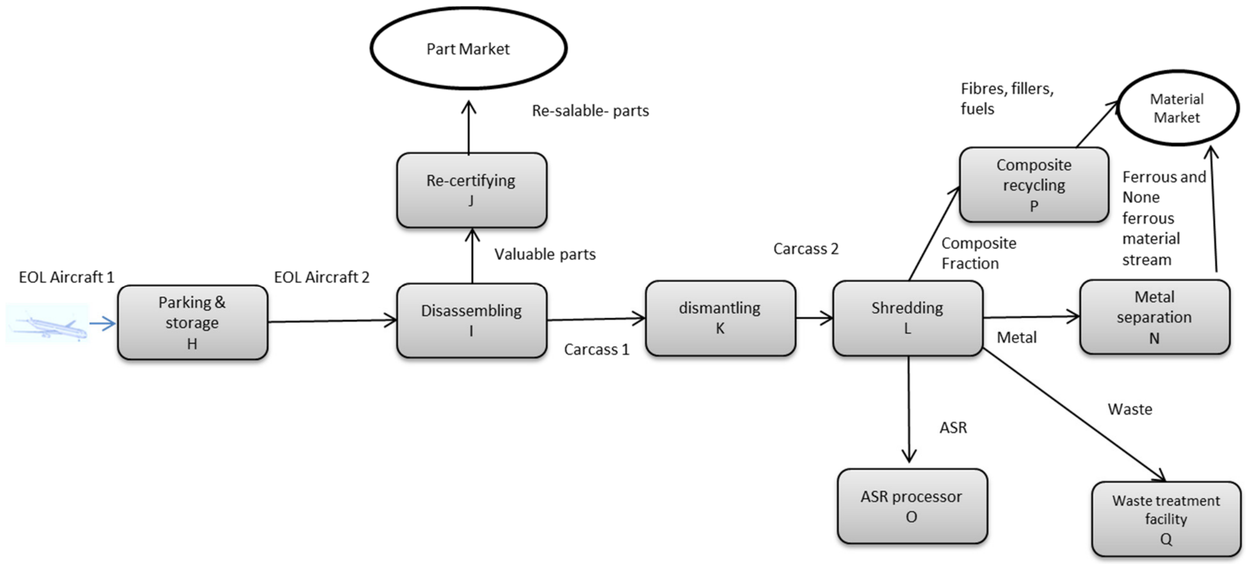


Figure 75 : The value chain of the EOL aircraft recycling

5.1.6.1.2. The geographical definition and the length of value chain

End of life phase of aircrafts may occur in different countries thus the management of the recycling needs to be considered in the global context. The different sub-processes in the recycling can be done locally or can be outsourced to the third party. Hence, the problem needs to be assessed and analyzed as a global value chain. Economics of scale as an important element in disassembly & recycling of discarded materials or environmentally friendly disposal of materials should be taken into account. Moreover, local authorities, environmental taxes and other global business factors need to be considered in the analysis of the value chain. For illustration purpose for example, the distribution location of some parts of the operation is shown in Figure 76.

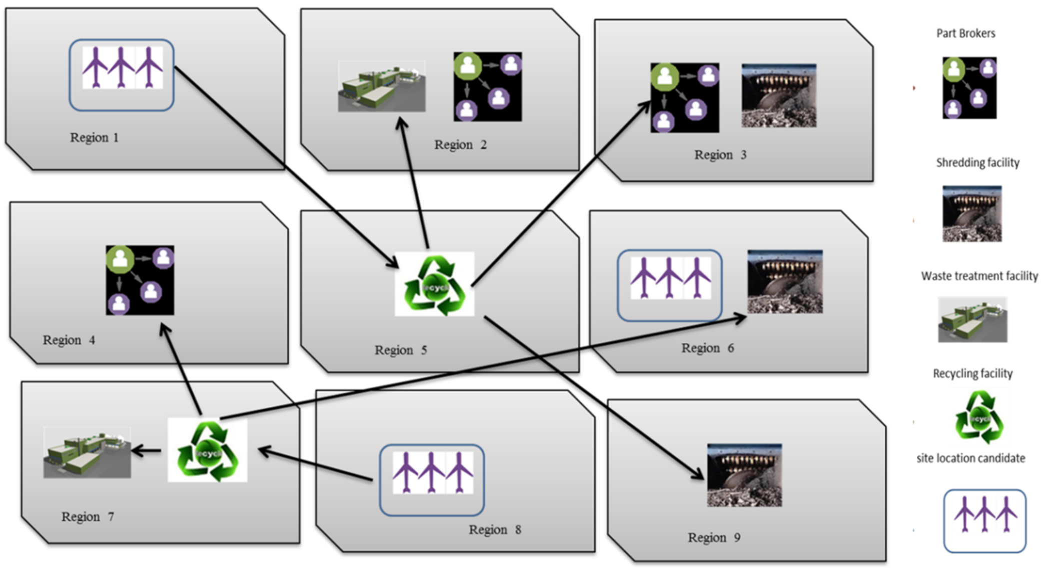


Figure 76 : Distribution location of the players

5.1.6.2. Step 2: sustainability analysis & value creation

Recycling operation of the EOL aircraft has several environmental and social impacts which need to be considered. Sustainability analysis of the value chain provides this opportunity to assess and quantify these impacts. Life cycle assessment of the whole process provides information about the environmental impacts of the different sub-processes including Noise, Air emission, solid waste,

addition, social impacts can be evaluated via different criteria such as Employment, risk to labour and local improvement. A panel of experts through a Delphi method can be used for estimation of the social impacts of different sub-processes.

Recently, there are some researches which study the sustainability flow analysis in the logistics and supply chain framework. The authors in [41] proposed the concept of cumulative eco-intensity with sustainability indicators related to the added value of economic activities. In this framework, the flows pass from supplier to supplier and therefore allow including upstream and downstream effects along the supply and waste disposal chain. A model for measuring reverse logistics social responsibility performance based on the Triple Bottom Line approach is proposed in [42]. This model used two numerical examples to test the validity of the introduced approach.

Figure 6 illustrates the exchange flows through value chain based on triple bottom line. The economic value of the agent can be estimated by the amount of material and its value which allocate to the next agent. Hence, for example H_M stands for the output flow of the material from agent H and H_V stands for the value of this stream. The environmental and social impact of this agent also is shown by H_E and H_S respectively. In this paper, in order to make simplicity, we used equation 5.1.1-5.1.4 to estimate the sustainability of the value chain. However, according to [43], which introduced a novel concept to integrate the value, value creation and realization and value captures, the value capturing process needs to be assessed in the power relationship framework of buyers and sellers. Hence, for example, as shown in Figure 77, the relationship among agent I, K and L is crucial in value exchange and value creation process. This issue needs to be considered in formulation of the economic value estimation and sustainability index of the value chain.

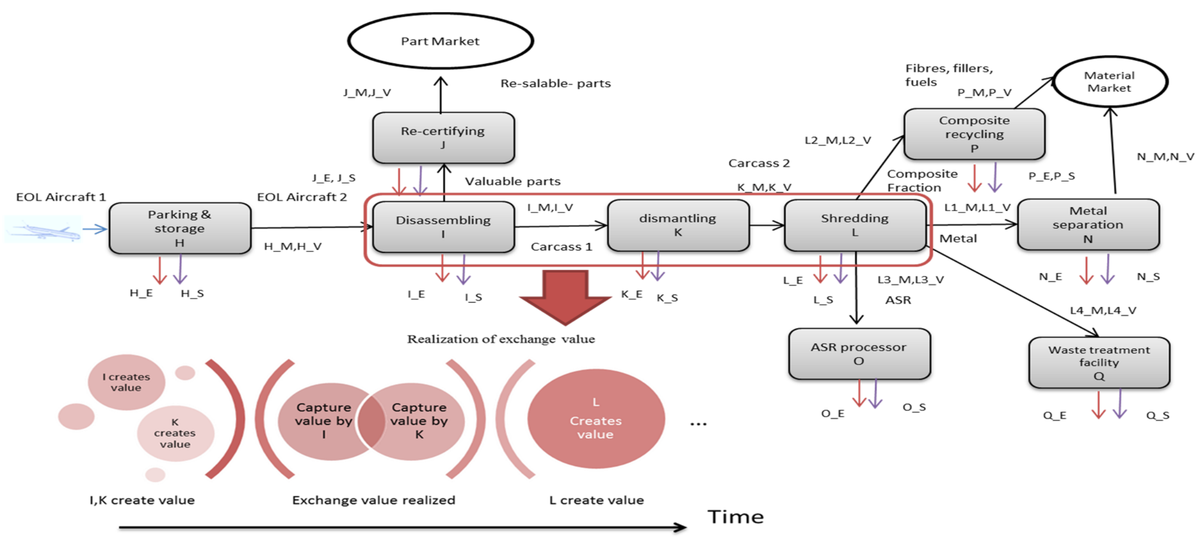


Figure 77 : The value chain of recycling with flows of sustainability and value creation challenge

$$ECV_{chain} = \sum_{\forall i \in \{H,I,J,K,L,N,O,P\}} i_M i_V \tag{5.1.1}$$

$$ENI_{chain} = \sum_{\forall i \in \{H,I,J,K,L,N,O,P\}} i_E \tag{5.1.2}$$

$$SCI_{chain} = \sum_{\forall i \in \{H,I,J,K,L,N,O,P\}} i_S \tag{5.1.3}$$

$$SUI_{chain} = \frac{ENI_{chain} + SCI_{chain}}{ECV_{chain}} \tag{5.1.4}$$

5.1.6.3. Step 3: players, policy and governance

This part goes into more details about the players, policy framework and the governance of the value chain. The distribution of power and decision making across the value chain and the framework for analyzing the policy and governance will be discussed.

5.1.6.3.1. Players and interaction

According to [6] various activities are involved in the EOL aircraft treatment which implies the involvement of different businesses and stakeholders. Waste treatment companies, aircraft owners (often comes to airlines and financial institutions), part brokers (or maintenance specialists), smelters, recyclers, or legal institutions. The key players of aircraft EOL problem and preliminary value map of their relationship network is shown in Figure 78. The different business actors or suppliers are shown with letters A to Q.

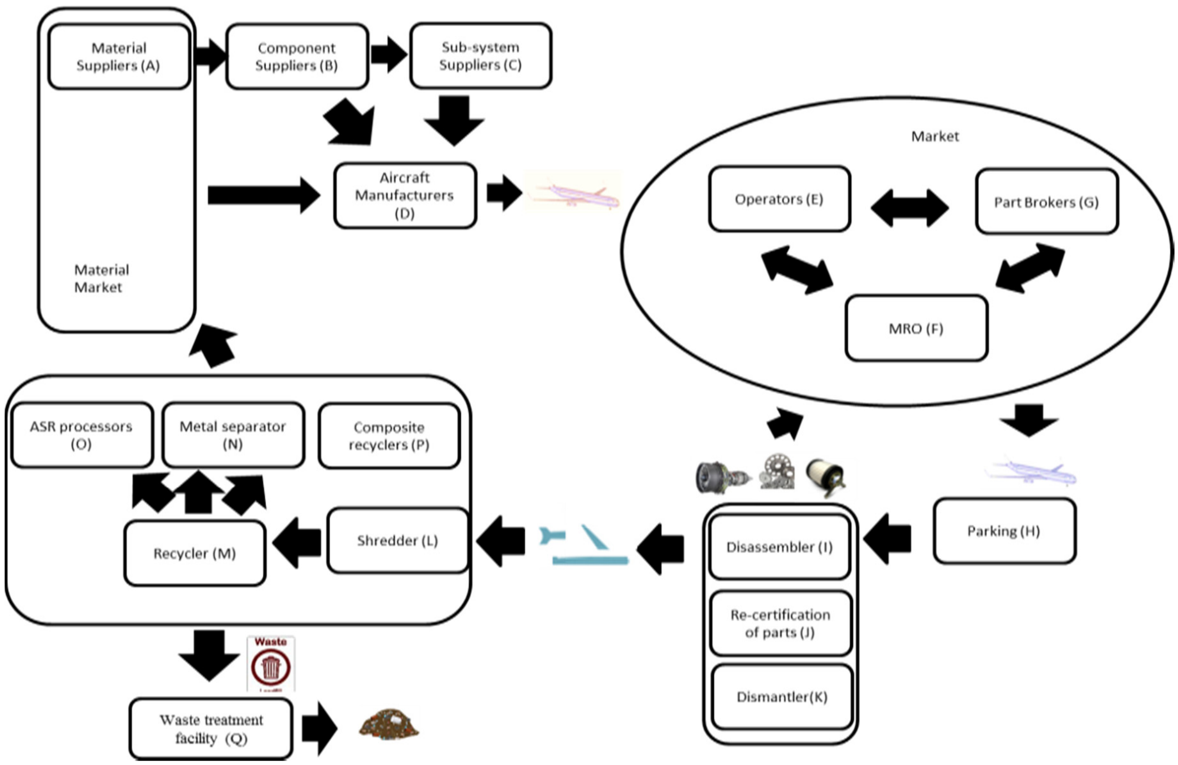


Figure 78 : The players in the value chain of EOL aircraft recycling

5.1.6.3.2. Policy framework and governance

When an aircraft is dismantled and recycled several regulations and laws should be kept in consideration [2]. Moreover, some special local rules and regulation needs to be applied as well as licences. Based on the involvement of the different players, identifying the policy framework can aid to internal consensus and also external authorities communication and reporting. The policy framework can be studied in four levels including the policy level, standards, best practices and guideline and finally procedures. Figure 79 shows the current policies in the framework of the EOL aircraft recycling.

The authors in [44] defines governance as ‘‘the relations, through which key actors create, maintain, and potentially transform network activities’’ (p. 728). We want to answer to this question that how the relationships among actors in EOL aircraft recycling value chain can be managed in order to aid of improving the sustainability performance of the whole. According to [45], there are different approaches for studying inter-organizational relationships and governance mechanism. Transaction cost theory; social network theory and global value chain analysis are the approaches for analyzing the governance mechanism in supply or value chain framework. Transaction cost theory determines factors in selection of exchange modes between actors [46]. Social network analysis focus on the all relationship in the network of the players and global value chain analysis covers power relationship and the information exchange. The authors in [45] with studying dyadic relationships between a buyer and the suppliers in supply chain and based on Transaction cost theory studied the governance mechanism in the supply chain and concludes that both mechanisms, supplier assessment and supplier collaboration, have the impact on environmental performance of supply chain. According to [47] the structure of the relationships among actors and position in a network affect sustainability interaction, sustainability commitment, collaboration and success. The work [48] studied the governance of organizational networks and the impact of governance on network effectiveness. They introduced three models for network governance and based on four aspects (trust, number of participants, goal consensus and need for network level competencies) examined and discussed the effectiveness of each of these models. The first mode is participant-governed networks which network members governed themselves without any external entity. Governance in this form can be achieved by regular meeting among partners or any uncoordinated efforts. In this framework involvement and commitment of all players are essential. Hence, the power is more or less symmetrical however, there may be some differences regarding resource capabilities or performance. The second mode is lead organization-governed mode that the network governance can perform with lead organization. In this mode, all major activities are coordinated by single member who act as a lead organization. Hence, in this model, network governance is highly centralized with asymmetrical power. The third model is network administrative organization which a separate administrative entity governs the network and its activities. In this form, the network broker plays an essential role in coordination of the network. This framework can reduce the complexity of shared networks. In the case of EOL aircraft recycling value chain, if we consider the sustainability goal consensus so the shared governance model or network administrative model may be valuable. In addition, the number of participants depends on the involvement of different players as third party for the sub-procuresses of the operation. If we assume the few to moderate players in the chain, with expected high density of trust which is available in aviation context, then the shared governance or network administrative organization are effective forms. The collaboration among the players and the procedure for selecting the entities may be considered as typical governance of the recycling value chain. However, assessing the effective format of collaboration is a separate study. For example, forming the matrix of collaboration among players and analyzing the power structure based on the social network theory is a sound method in this regard (For example see the Figure 80).

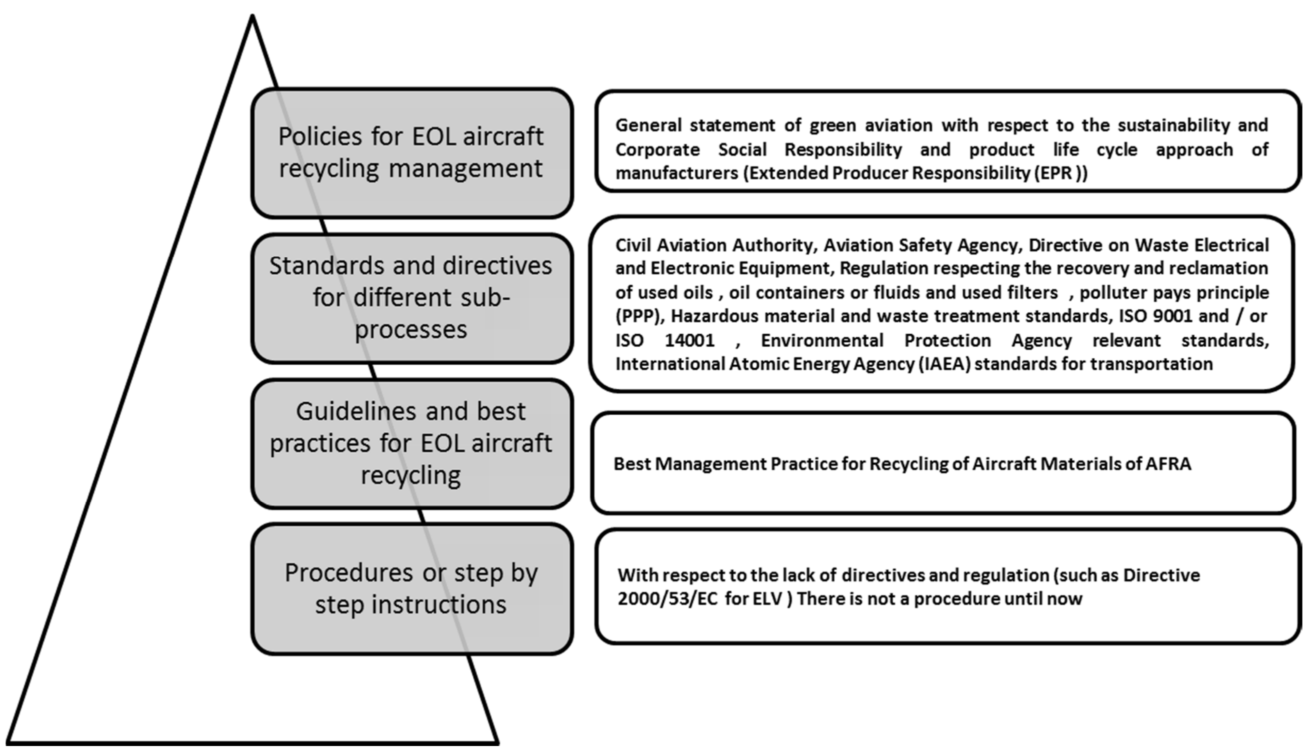
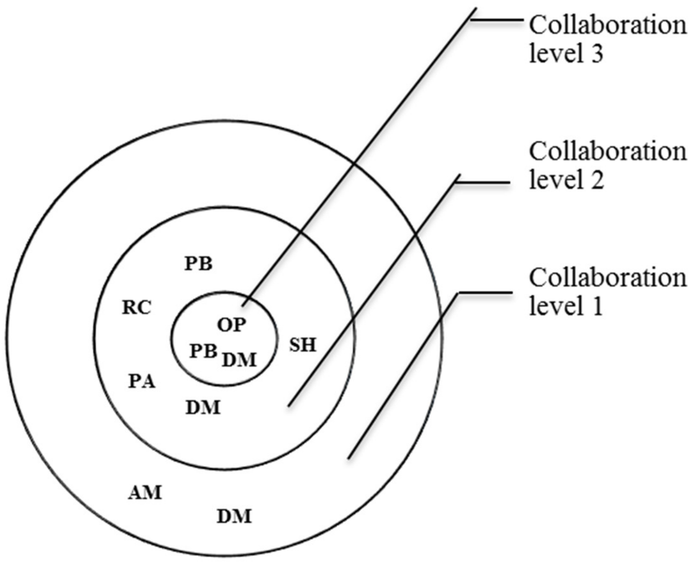


Figure 79 : Policy framework of the EOL aircraft recycling value chain



Players	Code
Aircraft manufacturer	AM
Operator/Owner	OP
Part broker	PB
Parking agent	PA
Dismantler	DM
Shredder	SH
Recycler	RC
Waste treatment agent	WT

Figure 80 : Example of collaboration among players for identifying the governance model of the recycling value chain (Level 1 may be limited to information sharing but Level 3 is a strong relationship such as a establishing a strategic alliance)

5.1.6.4. Step 4: performance measurement

The International Standards Office (ISO) has introduced a method for calculating the performance of the recycling of Road Vehicles. However, no model has defined for measuring performance within the aviation sector ([2] in [13]). This section reviews some indicators to evaluate the recycling value chain in details.

5.1.6.4.1. Effectiveness, efficiency and stability measurement

The first performance measurement is cost effectiveness of the whole process. The costs of recycling operation depend on different parameters. Total making of the process or outsourcing some sub-processes can affect the total costs. However, the transportation costs (depending on the mode of transportation) need to be considered. Labour costs are important element in dismantling and disassembling and depend on the skills and experiences of the labour. Moreover, the equipment, technology costs for sorting and material costs need to be considered. Figure 81 shows some of these costs across the value chain.

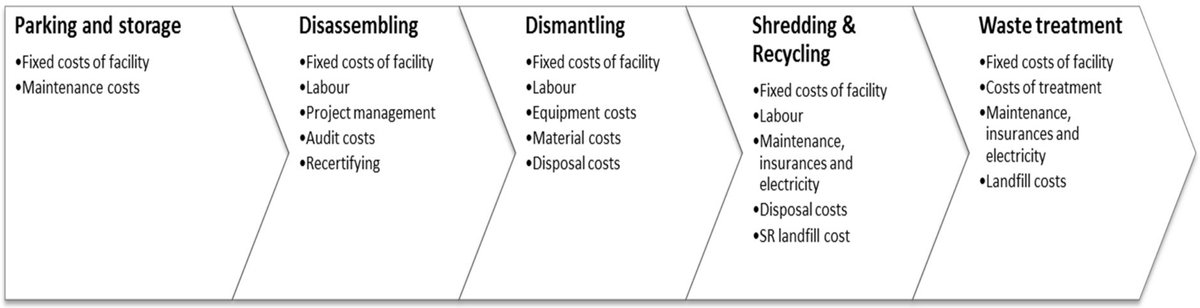


Figure 81 : The associated costs in each phase of EOL aircraft recycling

The recycling and recovery rate of whole process is another index for performance measurement of the value chain. The authors in [2] discussed the recyclability and recoverability rate of the EOL aircraft based on the Eq. 5.1.5-5.1.6. Which mv is vehicle mass, mTr is non-metalic residue treatment step as recyclable, mTe, non-metallic residue treatment step as energy recovery and mM Metal separation.

$$Rcyc = \frac{mM + mTr}{mv} \times 100 \quad (5.1.5)$$

$$Rcov = \frac{mM + mTr + mTe}{mv} \times 100 \quad (5.1.6)$$

The authors believe that these rates linked to the success of the recycling process. In addition, this amount can be different between an end-of-life recycling of a first aircraft of a model and one of the last of a model still flying. The potential of re-using the parts depends on the commonality of parts and the similar models which still being operated (p. 6).

Environmental and social performance of the process is the next indicator for evaluation of the performance of the operation. The sustainability index which discussed in section 5.1.4.2 can be utilized in order to measure the sustainability of the chain.

From the network perspective, the stability of the network is another index which can be used in performance measurement framework. There are different approaches for measuring network and chain stability. The authors in [49] studied the stability of supply chain. They concluded that the stability and effectiveness of supply chain is closely related to the capacity of the dominant or core-firm to plan the governance structure. However, the nature of the process also influences the networking process.

The authors in [50], with considering the buyer-seller relationship in upstream and downstream of a supply chain, defines the stable network as follows: "a network is chain stable if there is no upstream-downstream sequence of agents (not necessarily going all the way to the suppliers of basic inputs and the consumers of final outputs) who could become better off by forming new contracts among themselves and possibly dropping some of their current contracts". Hence, the governance structure of the network and the level of collaboration and selection of the third parties should be taken into account to evaluate the stability of value chain. If we look at the value chain as a set of several contracts among the upstream, midstream and downstream of the value chain, the stability measure of the social network and supply chain context can be applied (see the Figure 82)

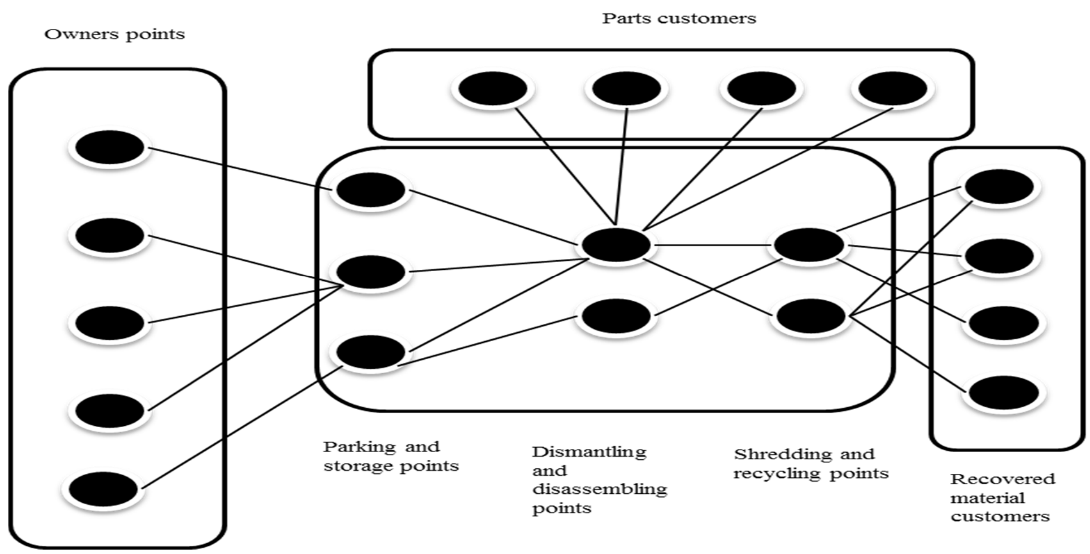


Figure 82 : Downstream, midstream and upstream of the EOL aircraft recycling value chain

The last indicator for performance measurement is growth and learning across the value chain. As discussed before, appropriate feedbacks in each sub-process of the operation can be valuable for aircraft manufactures for considering in design stage of future aircrafts. Moreover, the growth of the chain in order to act as an infrastructure for recycling in future (like ELV recycling infrastructure) can be the other indicator for evaluation of the whole process.

5.1.7. Conclusion

This study introduced a methodology for analyzing the value chain in the context of sustainable development. The value chain of the EOL aircraft recycling was selected to show the application of the proposed approach. This approach has four main steps: identifying the value chain and the problem context, sustainability analysis based on triple bottom line theory, identifying the policy framework and network governance and finally performance measurement in order to provide recommendations regarding effectiveness, efficiency and stability across the value chain. The implications of this study are both theoretically and practically. From theoretical perspective, it proves a starting point to develop an integrated framework for analysis the value chain in the context of sustainable development.

From practice view, it makes guideline for analyzing the process of EOL aircraft recycling. The application of the proposed framework via a case study is the research agenda for the authors.

References

[1] AFRA official website retrieved from http://www.afraassociation.org/

[2] Van Heerden, D. J., & Curran, R. (2011). Value Extraction from End-of-Life Aircraft. Encyclopedia of Aerospace Engineering. Wiley.

[3] Franz, K., Hörnschemeyer, R., Ewert, A., Fromhold-Eisebith, M., Böckmann, M. G., Schmitt, R., ... & Reichmuth, J. (2012). Life Cycle Engineering in Preliminary Aircraft Design. In Leveraging Technology for a Sustainable World (pp. 473-478). Springer Berlin Heidelberg.

[4] Sainte-Beuve, D. (2012). Évaluation de différentes stratégies de démantèlement de la carcasse d'un avion (Doctoral dissertation, École Polytechnique de Montréal).

[5] Latremouille-Viau, J., Baptiste, P., & Mascle, C. (2010). Airframe Dismantling Optimization for Aerospace Aluminum Valorization. In Frontiers of Assembly and Manufacturing (pp. 157-169). Springer Berlin Heidelberg.

[6] Siles, C. (2011). Aide à la décision pour la gestion d'un parc d'avions en fin de vie (Doctoral dissertation, École Polytechnique de Montréal).

[7] Air transport action Group (ATAG), http://www.atag.org/

[8] Airbus Environment Report (2013) retrieved from www.airbus.com/company/environment

[9] ICAO Environmental Report 2010 retrieved from www.icao.int/environmental-protection

[10] Antoine, N. E., & Kroo, I. M. (2004). Aircraft optimization for minimal environmental impact. Journal of aircraft, 41(4), 790-797.

[11] Romaniw, Y., & Bras, B. (2012). Survey of Common Practices in Sustainable Aerospace Manufacturing for the Purpose of Driving Future

Research. In Leveraging Technology for a Sustainable World (pp. 485-490). Springer Berlin Heidelberg.

[12] Rose, C. M. (2000). Design For Environment: A Method for Formulating Product End-Of-Life Strategies. Ph.D. Thesis, Stanford University.

[13] Keivanpour, S., Ait-Kadi, D., & Mascle, C. (2013). Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects, A Research Agenda in Transdisciplinary Context. Journal of Management & Sustainability, 3(3).

[14] Watson, M. (2009). End of Aircraft Life Initiatives, SBAC Aviation and Environment Briefing Papers. Retrieved fromhttp://www.sustainableaviation.co.uk/wp-content/uploads/end-of-aircraft-life-initiatives-briefing-paper -11.pdf

[15] Boeing 2010 Environment Report. Retrieved from http://www.boeing.com/aboutus/environment/environment_report_10/boeing-2010-environment-report.pdf

[16] Manzini, Raffaella; Giuliano Noci, Massimiliano Ostinelli and Emanuele Pizzurno (August 2004). "Assessing Environmental Product Declaration Opportunities: a Reference Framework". Business Strategy and Development **15** (2): 118–134

[17] Wimmer, Wolfgang; Rainer Züst, Kun-Mo Lee (2004). Ecodesign implementation: a systematic guidance on integrating environmental considerations into product development. Springer

[18] Bombardier Website http://csr.bombardier.com/en

[19] EPD of the SPACIUM train of Bombardier retrieved from http://csr.bombardier.com/pdf/Bombardier-Transportation-EPD-SPACIUM-en.pdf

[20] EPD of Volvo FH12 retrieved from www.**volvo**trucks.com/.../environmental-product-declaration

[21] Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). Value creation and value capture: A multilevel perspective. Academy of Management Review, 32(1), 180–194.

[22] Priem, R. L. (2007). A consumer perspective creation. Academy of Management Review, 32(1), 219–235.

[23] Garriga, E. (2014). Beyond Stakeholder Utility Function: Stakeholder Capability in the Value Creation Process. Journal of Business Ethics, 1-19.

[24] Freeman, E., Harrison, J. E., Wicks, A., Parmar, B., & Colle, S. (2010). Stakeholder theory: The state of art. Cambridge: Cambridge University Press.

[25] Post, J. E., Preston, L. E., & Sachs, S. (2002). Managing the extended enterprise: The new stakeholder view. California Management Review, 45(1), 6–28.

[26] Stuart L. Hart and Mark B. Milstein, Creating sustainable value, Academy of Management Executive, 2003, Vol. 17, No. 2

[27] Fasse, A. C., Grote, U., & Winter, E. (2011)Recent developments in applying environmental value chain analysis. Environmental Economics, Volume 2, Issue 3

[28] Tan, J., & Zailani, S. (2009). Green Value Chain in the Context of Sustainability Development and Sustainable Competitive Advantage: A Conceptual Framework. International Journal of Business Insights & Transformation, 3(1).

[29] Dahlström, K., & Ekins, P. (2006). Combining economic and environmental dimensions: Value chain analysis of UK iron and steel flows. Ecological Economics, 58(3), 507-519.

[30] Pesonen,H.L (2001) , Enviornmental amnagment of Value chain, promoting life cycle thinking in industerial networks, GMI 33 Spring 2001 Greenleaf Publishing

[31] Rose, C. M., Stevels, A., & Ishii, K. (2000). Applying environmental value chain analysis. Electronics goes green, Berlin.

[32] Potts , J., Global Commodity Chain Sustainability Analysis: Explanations and Examples , IISD , Retrieved from www.iisd.org/pdf/2007/global_commodity_chain_examples.pdf

[33] Porter, M. (1985): Competitive Advantage, London: Macmillan

[34] Gereffi, G. (1994b): The organization of buyer-driven global commodity chains: how U.S. retailers shape overseas production networks. In G. Gereffi and M. Korzeniewicz (ed.) (1994): Commodity Chains and Global Capitalism. Westport: Praeger, pp. 95-122.

[35] Faße, A., Grote, U., & Winter, E. (2009). Value chain analysis methodologies in the context of environment and trade research (No. 429). Discussion papers//School of Economics and Management of the Hanover Leibniz University.

[36] Savitz, A. (2013). The triple bottom line: how today's best-run companies are achieving economic, social and environmental success-and how you can too. John Wiley & Sons.

[37] Neely, A.D., Adams, C. and Kennerley, M. (2002), The Performance Prism: The Scorecard for Measuring and Managing Stakeholder Relationships, Financial Times/Prentice Hall, London

[38] Moullin, M. (2002), Delivering Excellence in Health and Social Care, Open University Press,Buckingham

[39] Keivanpour, S., Kadi, D. A., & Mascle, C. (2014). Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network. SAE International Journal of Materials & Manufacturing, 7(1), 73-83.

[40] Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. International Journal of Production Economics, 130(1), 1-15.

[41] Schmidt, M., & Schwegler, R. (2008). A recursive ecological indicator system for the supply chain of a company. Journal of Cleaner Production, 16(15), 1658-1664.

[42] Nikolaou, I. E., Evangelinos, K. I., & Allan, S. (2011). A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. Journal of Cleaner Production.

[43] Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. British Journal of Management, 11(1), 1-15.

[44] Raynolds, L. (2004). The globalization of organic agro-food networks. World Development, 32(5), 725–743.

[45] Gimenez, C., & Sierra, V. (2013). Sustainable Supply Chains: Governance Mechanisms to Greening Suppliers. Journal of business ethics, 116(1), 189-203.

[46] Williamson, O. E. (1975). Markets and hierarchies: Analysis and antitrust implications. New York, NY, USA: The Free Press.

[47] Vurro, C., Russo, A., & Perrini, F. (2009). Shaping sustainable value chains: Network determinants of supply chain governance models. Journal of Business Ethics, 90(4), 607-621.

[48] Provan, K. G., & Kenis, P. (2008). Modes of network governance: Structure, management, and effectiveness. Journal of public administration research and theory, 18(2), 229-252.

[49] De Toni, A., & Nassimbeni, G. (1995). Supply networks: Genesis, stability and logistics implications. A comparative analysis of two districts. Omega, 23(4), 403-418.

[50] Ostrovsky, M. (2008). Stability in supply chain networks. The American Economic Review, 897-923.

5.2. Developing an optimization model for EOL aircraft recycling value chain analysis in sustainable and global context (Part A: Integrated framework for strategic optimization)

5.2.1. Résumé

De nos jours, le nombre d'infrastructures dédiées au recyclage des avions en fin de vie est très limité. Cependant, les pratiques du développement durable sont devenues incontournables, ce qui pousse le secteur aéronautique dans le futur, à les considérer de façon systématique pour le traitement des avions en fin de vie. Cet article propose une approche globale du traitement des avions en fin-de-vie dans le cadre du Lean management, du développement durable et du Global business (commerce mondial).

Dans cet article, il est proposé un ensemble intégré de solutions d'optimisation comme outils d'aide à la décision qui interviennent au niveau stratégique et managériale. Cet ensemble est flexible, et est utilisé pour comparer différents modèles d'affaires, de stratégies de démantèlement, et de structures de réseaux différentes qui ont un impact sur l'efficacité, la stabilité et la finesse des réseaux de récupération. En outre, la récupération du matériel, la logistique et la gestion de la chaîne des valeurs des opérations de traitement sont intégrés dans le système pour fournir la meilleure stratégie de création de valeur compte tenu des mesures de développement durable avec l'intégration de l'ensemble des principales parties prenantes impliquées dans le problème. Dans la partie B de ce document, un modèle d'optimisation et des perspectives sont illustrés.

Mots-clés: traitement des avions en fin-de-vie (EOL), optimisation intégrée, développement durable, Global Business, gestion Lean

5.2.2. Abstract

Until now, there is limited number of dedicated infrastructure for recycling of the aircraft at the end of life. Sustainability and image concerns push aerospace sector to deal with end of life (EOL) aircraft problem in future in a systematic way. This paper proposes a holistic approach to EOL aircraft treatment considering lean management, sustainable development and global business environment. An integrated optimization framework is proposed to support decision making in both strategic and managerial level. The framework is flexible to compare different business models, dismantling strategies and network structures which impact the efficiency, stability and leanness of the recovery network. Moreover, material recovery, logistics and management of value chain of treatment operations are incorporated into the framework to provide the best value creation strategy considering the sustainability measures and the key stakeholders involved in the problem. In part B of this paper the optimization model and application perspective are illustrated.

Keywords: End of Life (EOL) aircrafts treatment, integrated optimization framework, sustainable development, global business, Lean management

5.2.3. Introduction

More than thousands of aircrafts will be retired in the next 2 decades. The recycling of these aircrafts provides several opportunities for aviation business. Moreover, considering the increasing focus of aviation community on environmental issues and landfill regulation, owners seek for efficient, economically and environmentally-sound methods for EOL aircrafts (AFRA). From the aircraft manufacturer's perspective, the green image related to treatment of aircrafts at the end of life based on environmental concerns shifted gradually as a competitive advantage in the global market (Siles, 2011). EOL aircrafts recycling can be considered as a significant financial windfall. Regardless of the resale of the reusable parts from aircraft, it is possible to make money from the recycling of materials. Furthermore, the reduction of the environmental impact of a retired fleet through recycling process has an important role for all actors in operation processes of recycling the EOL aircrafts. Moreover, such approach can ensure a long term social benefits. Indeed, the development of this sector and having an infrastructure for recycling can lead to many lasting jobs opportunities, which are the factors of social and local development (Sainte-Beuve, 2012). As the EOL happens across the world, selecting the locations for whole treatment or different sub-processes of recycling operations should be considered as a global logistics problem. Developing new strategies for dismantling and decision support relating to design and management of EOL aircrafts treatment in uncertain business environment also needs to be taken into account. The efficiency of the treatment operation in the context of lean thinking can be measured by its efficiency in creating value for all players involved in the problem. The value creation process is the process with three essential elements: value identification, value proposition and value delivery (Grossi, 2003). The value identification can be achieved by recognizing the stakeholders and their needs. The value proposition is a trade-off analysis to obtain sustainable value for each stakeholder and finally in delivery phase, it's needed to focus on the end customers and services realization. Hence, the EOL aircraft treatment needs to be considered in lean management context to study the needs and value perceived by all stakeholders in the problem, the trade-off analysis related to the different aspects of operation to attain robust and sustainable value for all players. Finally, satisfying the owner's expectation considering the extracted value from their assets at the end of the operation should be met. In this paper, the optimization framework for EOL aircrafts treatment is proposed based on an integrated approach to lean principles, global business and sustainability goals. The present paper deals with questions regarding which business model for treatment operation is more appropriate in order to generate sustainable outcomes for stakeholders. An optimization framework is proposed for the optimal strategic decisions considering the material flow, process, locations of sub-process of treatment, network of players and value chain management of recovery operations. The remaining part of the paper is organized as follows: a literature review regarding EOL aircraft treatment studies is provided. Next, the optimization framework is presented and finally the main conclusion and the future research directions are described.

5.2.4. EOL Aircraft Management

Van Heerden & Curran, (2011) addressed the topic of value extraction from EOL aircrafts. The authors tried to answer five important questions about the recycling of aircrafts: why, when, what, who and where. They focused on the process of EOL aircraft recycling, the components as well as its economics. Franz et al., (2012) provided an assessment of life cycle engineering in preliminary aircraft design. They proposed an interdisciplinary approach in order to integrate the sustainability issues in aircraft design stage. With respect to the recycling and disposal phase, they considered the "Ladder of Lansink" approach to the aircraft dismantling which already proposed by (Van Heerden & Curran, 2011). In this approach, the first choice from environmental point of view is using the aircraft parts in other aircraft which still being operated. If reusing cannot be applied, the recycling or down-cycling (which refers to chemically combined or physically joined parts) is the choice. If these options cannot be done due to technological restriction then energy recovery by burning can be the solution. And finally, in the event that none of these options are available, landfilling is the last option. Sainte-Beuve, (2012) evaluated different strategies for skeleton dismantling of the aircraft. This work examined the difficulty of skeleton recycling due to use of mix materials. The author believes that recycling the skeleton is not a process with very high added value, such as parts reselling, though smart sorting can increase the extracted value from this operation. Latremouille-Viau et al., (2010) proposed a mathematical model in order to optimize the effectiveness of the aircraft dismantling process. This research studied which parts must be sorted before shredding and which units need to be shredded directly. Siles, (2011) developed a decision tool in order to maximize the profit of dismantling process with respect to the sorting stages. This work considered different scenarios for dismantling and introduced a mathematical model in order to show that which scenario can be chosen depending on available time, costs and revenues related to the scenarios. Keivanpour et al., (2013) purposes a research agenda that support various aspects of dynamics of EOL aircraft recycling projects. They developed a strategic framework with four parts: business model, market and industry, knowledge management and performance measurement make to address the important issues related to EOL aircraft projects. The authors in another study (Keivanpour et al., 2014) proposed a guideline for Aircraft manufacturers to select the best set of design for end of life techniques considering all stakeholder's needs and expectations. Keivanpour et al., (2014) also provided a conceptual framework for value chain analysis of EOL aircraft recycling process in the context of sustainable development. The synthesis in this literature reveals that there is not an integrated approach to EOL aircraft recycling which cover sustainability, global business and value creation concepts at the same time. Moreover, the logistics network management considering economic, environmental and social parameters and optimization of whole recovery process has not been addressed systematically.

5.2.5. Optimization framework

In this section, we develop an optimization framework to model the strategic design of EOL aircraft treatment considering global environment, lean thinking and sustainability objectives. Before demonstration of this framework, the process of treatment, involved stakeholders, the current business models and the global business aspect, lean management and sustainability feature of the problem will be described in order to provide the insight into the building blocks of the optimization framework.

5.2.5.1. EOL aircraft treatment

Before introducing the optimization framework, it is essential to understand the key steps in the management of the aircraft at the EOL. The first step of dismantling is de-pollution, cleaning and decommissioning of the aircraft. The fluids and kerosene must be drained and the tanks and batteries or some electrical materials must be removed (Siles, (2011). The next step is disassembling which include recovery of the parts and components. Dealing with the second hand parts is crucial and difficult task because there are a lot of regulations are associated (Van Heerden & Curran, 2011). Recertification of the parts is a separate activity which requires special equipment and personnel. For example, for European Aviation Safety Agency this step must be performed under the Part 145 standards. Depending the regions authorities, the other certifications may be required (for example: Part 571 of Canadian Aviation Regulation). The recovered parts can be classified in different categories (serviceable or unserviceable parts (Van Heerden & Curran, 2011), serviceable, repairable or bug parts (Siles, 2011)). Trading of the resalable parts can be done by part-brokers or the company who is in charge of the dismantling operations based on the business model. Then the skeleton of the aircraft is ready for dismantling process. In this step, the remaining structure and parts including the fuselage, wings, or the tails then more cleaned (stripped of carpets, luggage compartments, interior plastic walls, etc. ...) and then chopped up. Scrap obtained is finally crushed and sorted with different levels of detail according to the responsible company decision and then sent to smelters for final metal recycling (Siles, 2011). The shredding process is comparable with car recycling. Several technologies can be used in order to separate the different kind of materials (Van Heerden & Curran, 2011). What is remained must be sent to the waste treatment facility for energy recovery or disposal. Figure 83 presents the overall process of EOL aircraft treatment.

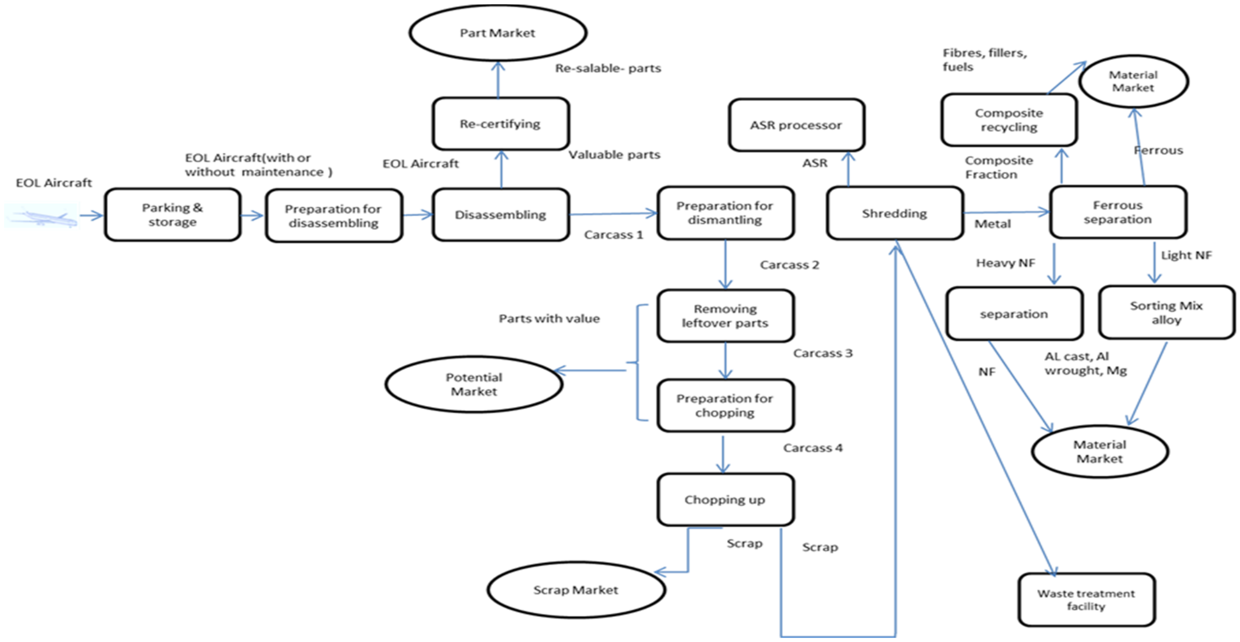


Figure 83 : The EOL aircraft treatment overall process

5.2.5.2. Stakeholders in value chain of EOL aircraft treatment

There are different players in novel EOL aircraft industry. The organization and services of these players depend on the circumstances. Some companies may perform several activities and services (Siles, 2011). In this sub-section, an overview of the different players in the sub-process of EOL treatment will be given.

5.2.5.2.1. Owners

Aircraft owners are often airline or financial institutions. When we talk about the owner in the category of stakeholders, we mean the "EOL aircraft problem owner". When the owner finds that aircraft operation is no more acceptable, it faced by several choices. The first option is selling aircraft as whole. If this option is not possible, it can remove the valuable parts and scrap the remaining structure. The other solution is removing the part as needed when there is a demand for the parts. So it needs to store the aircraft for a long period. The parking and storage is often expensive and its environmental impact is also another concern. There is a trade-off analysis with respect to the economic value of the decision and its environmental impacts. Hence, the objectives of the owner, the context of decision for example the regional authorities or the need for environmental friendly action is essential factors for the strategic decision regarding the dealing with the EOL aircraft. In the absence of EOL directives in aerospace industry (until now), it is obvious that the decision must be economically viable for the owner. Therefore, the cost efficiency of the process, the recovered values from the resalable parts or the remaining parts of the aircraft are important for this stakeholder. If the owner has specific corporate social responsibility and environmental impacts of its operation is important (for example green airlines) then the ecological consideration also needs to be considered.

5.2.5.2.2. Consultancy

There are some companies which provide solutions for the EOL aircraft. These companies compare the different options of owners and aid them in decision making process in order to select the best choice. For example, Aircraft End of Life solutions (AELS) and Evergreen Air Center provide consultancy for owners with respect to EOL aircraft solutions.

5.2.5.2.3. Parking and storage

Long term storage of the EOL aircraft needs specific conditions and requirements. The conditions must provide minimum of deterioration and corrosion. Usually, deserts are appropriate candidate for storing the aircrafts. Châteauroux Airport in France, Phoenix Goodyear Airport and Tucson International Airport in US have the facility for long term storage of the aircrafts (Van Heerden, 2005).

5.2.5.2.4. Dismantling facility

Disassembling is key sub-process in treatment operation. Hence, often the company, who is in charge of this process, design and manage whole recycling activities. Before disassembling, several processes must be done including (decontamination, cleaning and preparation). The retrieved parts after disassembling are stored in the stock of retrieved parts. Parts testing and sorting in different categories (serviceable, repairable, etc.) are performed by this company. Sometime, recertification and trading the valuable parts are also provided by this company. Chopping up operation, scraping and further sorting may also offer by them. For example, ASI, EVERGREEN TRADE INC, BARTIN AERO RECYCLYING and TARMAC AEROSAVE are companies which provide these services.

5.2.5.2.5. Trading the parts & components

The re-salable parts and components may be sold to part dealing companies for trading. Spare part dealers or part broker companies provide services for marketing process of retrieved parts in the second hand part market.

5.2.5.2.6. Pre-shredding services

Pre-shredding is a special step in EOL aircraft treatment. There are not many companies that are specialist in this domain. In this step the aircraft is prepared for chopping up. This phase can be an extension of the dismantling process for further sorting or removing more parts from aircrafts (such as interior). The trade-off analysis for this step is essential because sometime the companies start scrapping without any further sorting or removing the leftover parts (Van Heerden, 2005).

5.2.5.2.7. Shredding & Recycling facility

After pre-shredding step, the cut components will send to shredding facility to be crushed in smaller size and prepared for material recovery. Recycling the metal from EOL aircraft is a profitable business but due to higher levels of impurities in aircraft aluminum alloys and other performance characteristics (Das & Kaufman, 2008), the technology and method for recycling is important factor. The size and utilized method and technology for shredding and recycling are essential parameters in design of network recovery. It should be noted that considering the percentage of composite in future aircraft, the efficient composite recycling is also lead to resource saving and energy recovery. According to (Yang et al., 2012) extensive R&D efforts are still needed on development of ground-breaking better recyclable composites and much more efficient separation technologies. It is believed that through the joint efforts from design, manufacturing, and end-of-life management, new separation and recycling technologies for the composite materials recycling will be available and more easily recyclable composite materials will be developed in the future.

5.2.5.2.8. Manufacturers

Aircraft manufacturers are also key stakeholders in this business. Involving in the treatment process of the aircraft makes this opportunity for them to evaluate negative environmental effect of aircraft storage and dismantling phase and provide some valuable feedback for future design. Airbus initiated a PAMELA project with recycling and recovery rate by 85 percent of an aircraft weight. Boeing has taken a leadership role in aircraft life cycle and end-of-service recycling strategies for more than 50 years. Aircraft Fleet Recycling Association, AFRA, is a global consortium of more than 40 companies that provides environmentally responsible options for aging aircraft (Keivanpour et al., 2013-a). Bombardier (Bombardier website) is also working on recycling challenges. In 2011, this company continued its partnership with the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ), as well as the other research centers and universities to better understand end-of-life requirements and commercially practical recycling technologies for aircraft (Keivanpour et al., 2014).

5.2.5.2.9. Authorities

At the moment, there is not certain legislation regarding recycling and disposal of the aircraft. Hence, each company use its own business model or process for treatment of EOL aircraft. They only need to comply with the standards and legislation applicable in different sub-process of treatment operation or imposed by local authorities. Civil Aviation Authority, Aviation Safety Agency, Directive on Waste Electrical and Electronic Equipment, Regulation respecting the recovery and reclamation of used oils, oil containers or fluids and used filters, Hazardous material and waste treatment standards, ISO 9001 and / or ISO 14001, Environmental Protection Agency relevant standards, International Atomic Energy

Agency (IAEA) standards for transportation are standards and directives for different sub-process of treatment. It depends on the country where the dismantling process will be executed which licences are needed. However two issues will need attention, environmental and labour conditions.

5.2.5.2.10. Other stakeholders

There are other stakeholders in EOL aircraft problem. In addition, there are some companies in the business market of EOL aircraft which use the aircrafts in a creative ways (in internal decoration such as Jet engine as Cowling Bar). For example, using the parts of old aircrafts in the museums or in interior decoration are the other valuable usage of the retired aircraft parts and components. Labour, research centers, media, MRO and local residence are also the other stakeholders.

5.2.5.3. Different business models

According to (Siles, 2011) there is not a dominant business model related to EOL aircraft management. However, the way companies manage both types of products (spare parts and scrap) and the activity through which they make their profits could be explained by the core business of the company. This study identified three types of business models for EOL aircraft dismantling. In the First type, the focus is on part and equipment management. The companies with this type of business model focus on the removal of parts and all related activities for their return to flight: paper management monitoring, re-certification, logistics, marketing and sales. The treatment of the skeleton is transferred to another company. The second type focuses on the remaining parts of the planes. The core business of the companies in this category is recycling. In the last business model, the main motivations are legislations and environmental issues. For example, aircraft manufacturer get involved in this industry to obtain a green image. The priority seems to be the environmental aspect of the aircraft treatment at the end of life.
The author noted that the novel nature of the industry as well as confidentiality concerns do not let to access to the data to compare the profitability of each type of these business models. Latrémouille-Viau, (2009) studied the different business models of the companies in the aerospace industry involved in dismantling

operation. We considered four specific business models based on the information in this study. In the first model (Figure 84, left/up) there is a main enterprise that is in charge of dismantling operations. We named this enterprise “EOL enterprise”. The sub-processes of the treatment including storage, preparation & cleaning, disassembling, parts recovery, recertification and trading parts are also done by the company. The waste stream will be sent to waste treatment facility and recovered materials also will be sent to the appropriate channels. In the second business model (Figure 84, right/up), the parking and storage services (may include the maintenance or not) and trading the parts will be outsourced to the third party. The other sub-processes will be done by EOL enterprise in this model, the waste treatment is also done by the company and after this step and the disposals will be landfilled.

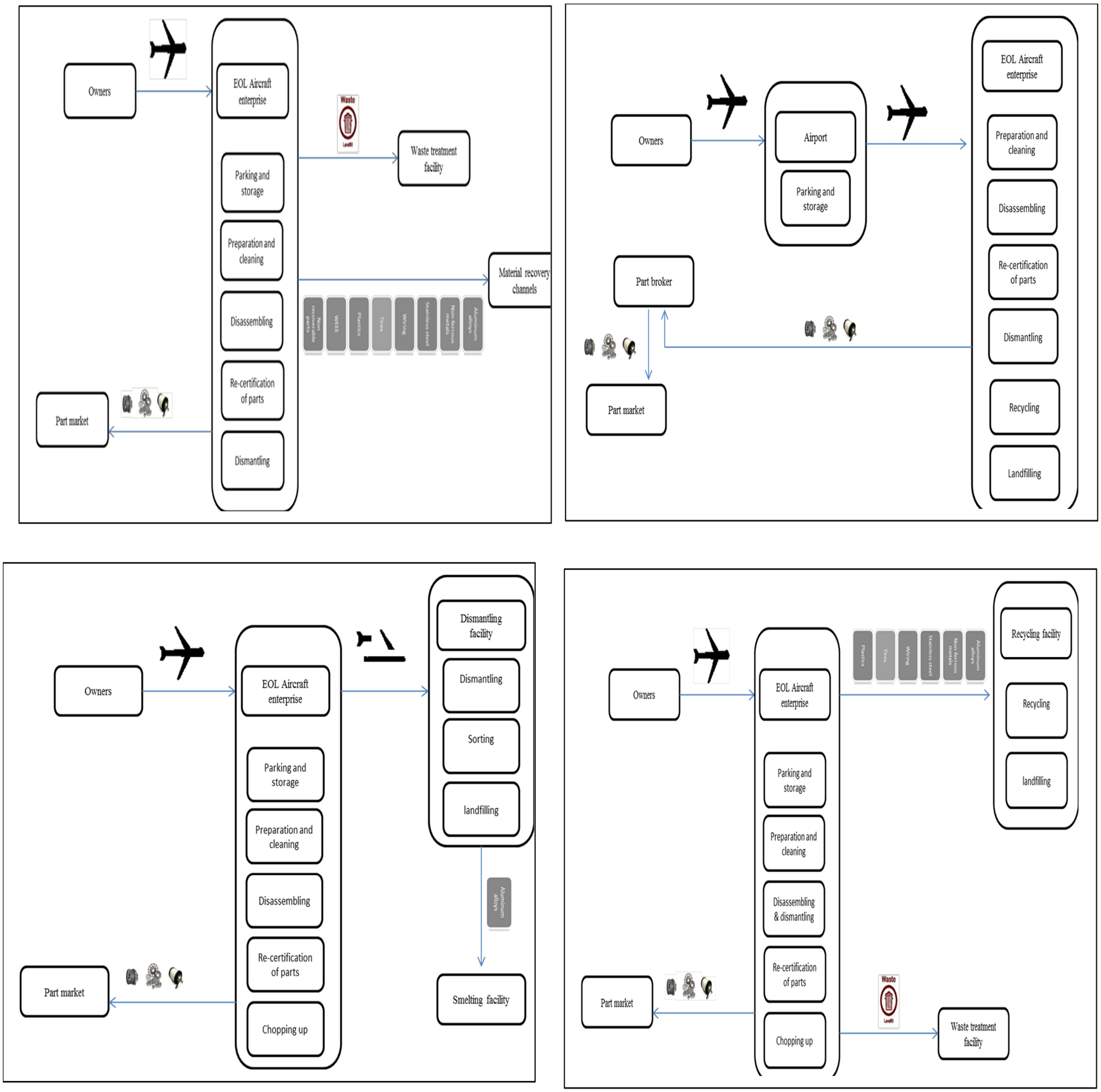


Figure 84 : Four General business Models for EOL aircraft treatment

In the third business model (Figure 84 left/down), EOL enterprise performs the storage, cleaning, part removing, trading the parts and components as well as chopping up the skeleton. Then, it sends the crushed parts to the dismantling facility to be more sorted. The aluminum alloys will also be sent to smelting facility for recovery. In the last business model (Figure 84 right/down), in addition to the sub-processes in third business model, EOL enterprise also performs dismantling and sorting and the stream of the material will be send to recycling facility in order to be prepared for trading in scrap market. Hence, based on these business models, some scenarios and cases could be assumed. The first option is to do the whole sub-process operations by EOL enterprise. Waste treatment, parking and storage, trading the parts and components; further dismantling and recycling can be outsourced to the third party. The steps for dismantling and sorting and the material stream also could be varied. Now, the question is that which business model is more suitable considering sustainability objectives, lean management philosophy and global business environment. The details regarding these aspects will be explained in the next sub-sections.

5.2.5.4. Optimisation context

As we mentioned in the previous parts, the main contribution of this paper is considering the optimization of EOL aircraft management problem in the context of lean, sustainability and global business simultaneously. In the next sub-sections we describe the different dimensions of the problem in these three contexts.

5.2.5.4.1. Global business environment

EOL aircraft problem may happen in different countries. The different sub-processes in treatment could be performed locally or outsourced to the third party. These third parties distributed around the world. Thus the management of the treatment operation needs to be considered in the global context. Figure 85 shows the geographic place of parking facilities, dismantling, selling components, pre-shredding and recycling. Allen & Raynor, 2004 highlighted the key factors in international business environment. Based on this study, the parameters which impact the EOL aircraft treatment are included trade agreements, international transportation, taxation, industry regulation, health and safety regulations, economies of scale, technical standards, business practices and corporate governance policy.

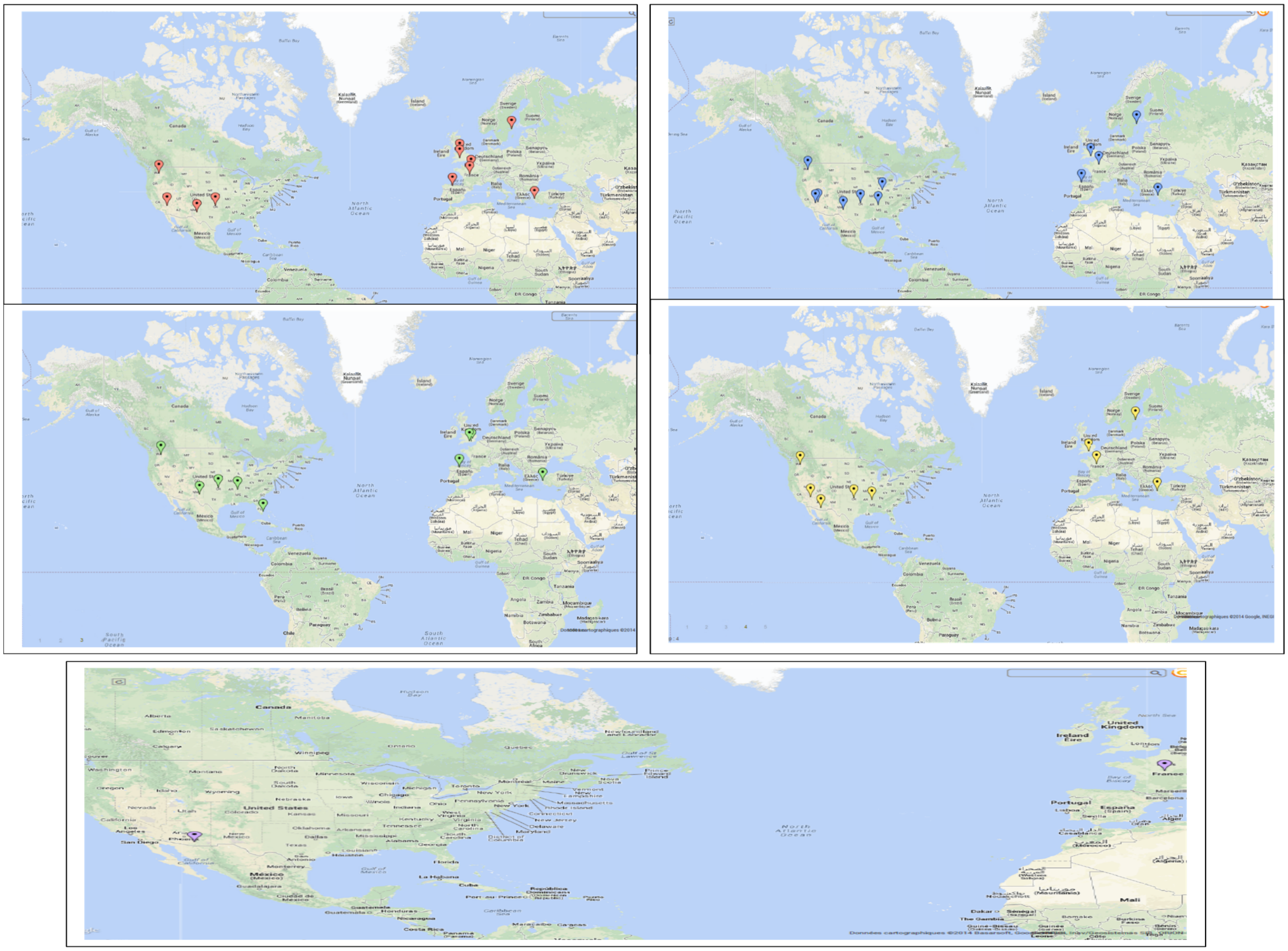


Figure 85 : The geographic place of parking facilities (Red), dismantling (Blue), selling components (Green), pre-shredding (Yellow) and recycling (Violet)

5.2.5.4.2. Lean management

According to (Grossi, 2003, p.11) a lean enterprise is an integrated entity which efficiency creates value for its multiple stakeholders by employing lean principles and practices. Therefore stakeholders are important to implement the lean principles. Lean principles are based on definition the value to the end of customer, identifying the value in order to eliminate the wastes, producing based on the demand and finally continuous improvement. Hence, in analyzing the value creation through the sub-systems under the study, the stakeholders and their relationship are essential element. Value creation activities and processes must be understood based on the firm's essential relationships with its stakeholders. MIT lean Aerospace initiative, defines the lean enterprise as an interconnected organizations with related activities and common business objectives (Grossi, 2003). Keivanpour et al., (2014-b) proposed a framework for the value creation process of EOL aircraft recycling process. The drivers are included the regulation, stakeholders needs and expectation, image and competition in aviation industry. The outcomes are comprised growth, innovation as the result of novel technologies and processes, cost effectiveness and reputation. Hence, the outcomes extracted from different sub-processes of recycling produces value for actors in the business loop. The value added process can lead to actor's satisfaction and this satisfaction is the source of the actions and activities that re-generate the value in the process.

5.2.5.4.3. Sustainable development

Recycling operation of the EOL aircraft has several environmental and social impacts which need to be considered. Sustainability analysis of the value chain provides this opportunity to assess and quantify these impacts. Life cycle assessment of the whole process provides information about the environmental impacts of the different sub-processes including noise, air emission, solid waste, waste of transportation and surface water and hazardous material impacts. In addition, social impacts can be evaluated via different criteria such as Employment, risk to labour and local improvement. A panel of experts through a Delphi method can be used for estimation of the social impacts of different sub-processes.

5.2.6. Conceptual framework for optimization

Based on the three contexts described above, we introduce a novel framework (Figure 86) for optimization of EOL aircraft treatment problem. This part goes into more details about the different sub-sections of the proposed framework. The framework has two levels: strategy level and management level. The area for optimization in each part will be described in details before model formulation.

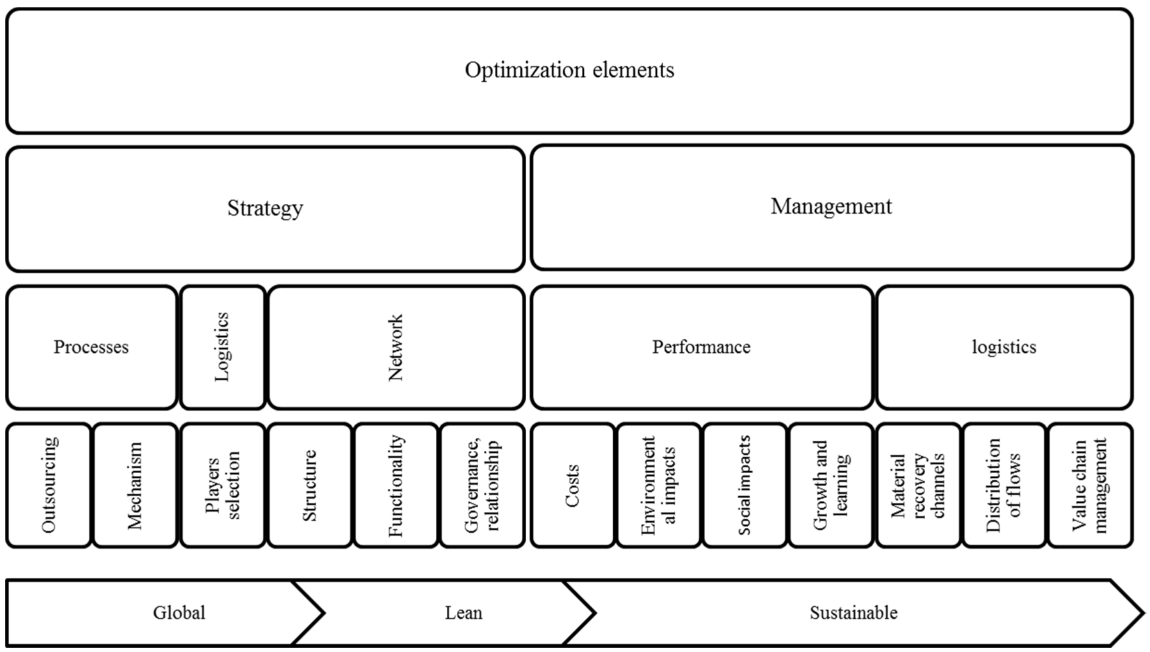


Figure 86 : The optimization framework

5.2.6.1. Strategy level

There are a couple of strategic decisions which should be addressed. Developing new strategies including global logistics of the dismantling and the proposition of dismantling strategy, the structure of recovery networks and the relationships among players are strategic decisions in holistic optimization framework. According to Cetinkaya et al., (2011), competitive strategy is a complete and long term plan that is capable to guarantee profitability considering the business environment. In addition, based on Porter's theory, corporate strategy address two critical questions: the type of business and corporation management. With respect to EOL aircraft treatment we face two questions, the type of business model which should be designed and the type of corporation considering the industry context. This strategy provides directions for developing the whole value chain and improving operational performance. The strategy should be integrated with key stakeholder's business strategies to maintain the overall mission of EOL aircraft management in three dimensions of global, lean and sustainability.

5.2.6.1.1. Process

After removing the part, there are several options for dismantling. According to (Siles, 2011) at one extreme, the dismantler can send the carcass to a junk yard directly, without making any further treatment. Carpets, plastics, cables and other remaining parts are crushed with the rest. On the other side, deliberated dismantling is possible, where as many items will be removed before chopping up. Between these two solutions, there are many options which may be considered. In all options, preparation phase for dismantling should be done considering the environmental impacts of hazardous materials or fluids. After this step, decision makers face to the different choices. According to Van Heerden & Curran, (2011) the aircraft may be scrapped and the smaller bits transported to a recycling facility for further sorting and shredding. Another choice is to previously sort different kind of materials before the chopping up from different waste streams. Decision making regarding this issue depends on the trade-off between economic value and environmental impacts. Moreover, the availability of technology for sorting at the shredding and recycling facility must be taken into account. Li et al., (2011) presented an optimization model to evaluate efficient sorting strategies. They mentioned that sorting technology performance, costs and market elements such as supply of mix of scrap and the demand are influential factors that determine the added value of different sorting technologies. Figure 87 presents the problem of selecting best sorting strategies for EOL aircraft. After stage 0, decision making regarding stage 1 or two or further stages of sorting is an essential problem which should be addressed properly. Moreover, after dismantling, the decision regarding scrapping or transferring the crushed parts to recycling facilities must be considered.

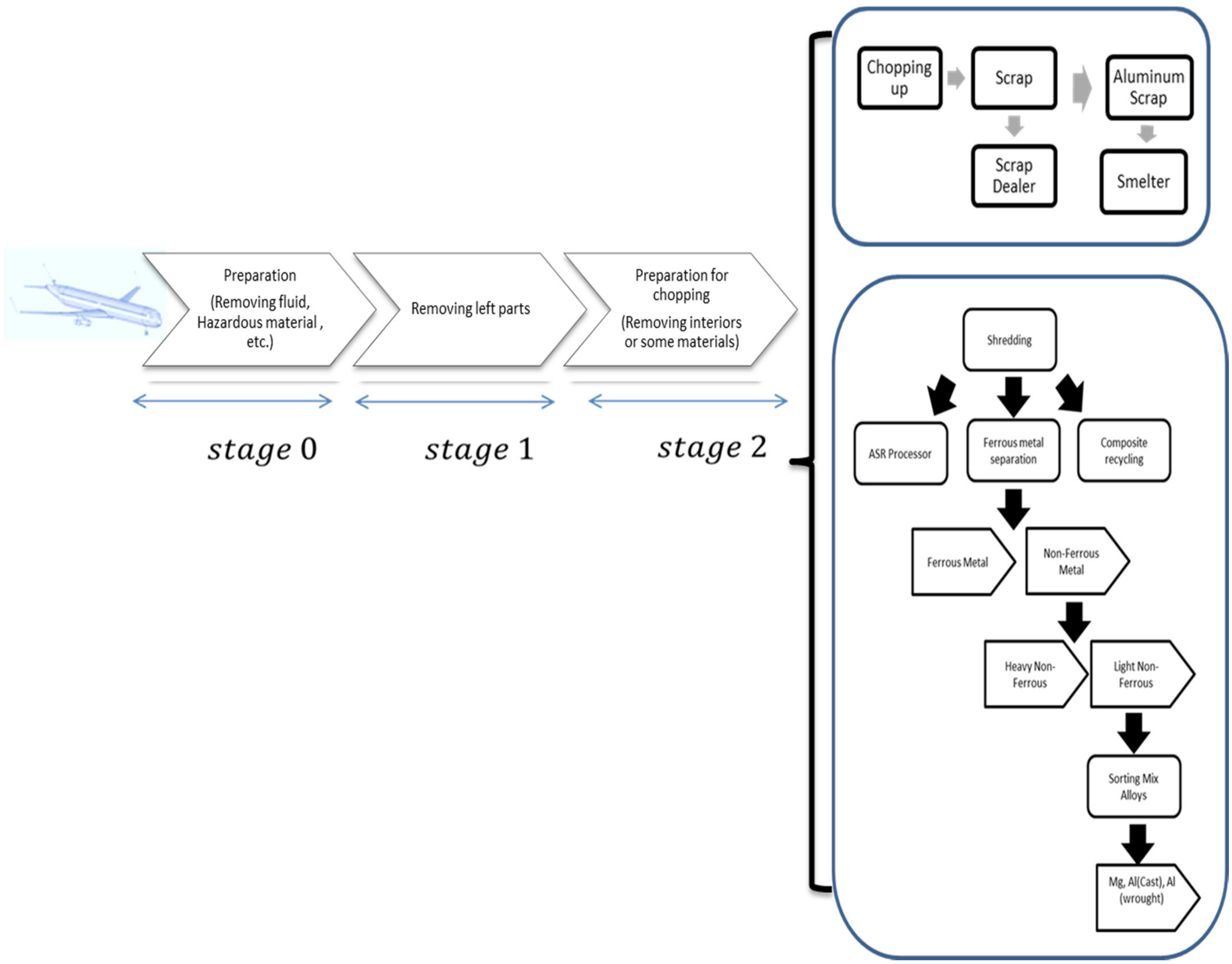


Figure 87 : Dismantling strategy problem

5.2.6.1.2. Logistics

Strategic decision regarding the logistics in EOL aircraft management relates to the partners which will be selected and the markets that be chosen to be served (part & component markets, material markets). Decision about Geographic scope of these partners and markets (as they are dispersed geographically around the world) can be addressed as a strategic decision making. In addition, the decision regarding the facility location of EOL enterprise should be discussed in this level of optimization. In addition to the firm's location and the governance of the involved parties, the mechanism and economic of the operations among them are important factor in waste management problems (Lynos, 2007). In strategic level, further to logistics decisions which have a rich literature in ELV recycling context, the network structure and governance policy are also taken into account in this study.

5.2.6.1.3. Network

Social network analysis literature covers different measures and functions which can be used in order to study the networks structure. According to (Keivanpour et al., 2014-a) in this literature, there are three categories of the study. Network representation is the first one which provides the knowledge about the players and their relationship. The second category is strategic formation which reflects two types of challenges in modeling networks from strategic perspective. Modeling the costs and benefits of various networks and how the player's value translates into network outcomes. Third group is network implications. This question that how the structure of network can affects learning and information diffusion is considered in this category. The first part of stakeholder network analysis is identification of stakeholders, their needs and expectations. After this step, the power of stakeholders or their priorities in the network should be identified because this issue can determine the influence of stakeholders in decision making process. Mitchell et al., (1997) proposed a model for stakeholder's salience. In this model the salience of the stakeholder can be determined by its power, legitimacy and urgency. Grossi, (2003) proposed a methodology in order to quantify the salience of stakeholders. We utilized this method in order to calculate the weight of stakeholders (who are responsible for decision making, set goals and objectives and trade-off analysis). In order to analyze the structure of the network, relationship degree, network density centrality and dependency can be used. Finally, for measuring functionality of the network (Grossi, 2003), information centrality proposed by Stephenson & Zelen

(1989) can be utilized. Table 25 shows the network measures which will be used in this study, their definition and applications.

The dependency of stakeholder is an essential element in determination of the governance and cooperation in the network. Grossi, (2003) utilized dependency structure Matrix used by Eppinger et al., 1994 in order to analyze dependency in stakeholders network structure. This matrix consists of N×N elements which reflect the relationship among nodes. When the stakeholder i maintain a relationship with stakeholder j a_{ij} is 1 otherwise is 0. The proposed methodology provides a mechanism for clustering the dependency matrix somehow to reveal the groups in the network. With this methodology the key stakeholders and key relationship can be found. Figure 88 illustrates a dependency structure matrix analysis in the network of stakeholders. With this approach we can find the important sub-groups in the network and essential relationship.

Table 25 : Stakeholder network applicable measures

No	Measure	Definition	Formula	Application
1	Stakeholders Salience	This index can help to prioritize the stakeholders. Which stakeholder is more powerful and have more impacts on the others (Mitchell et al., 1997), (Grossi, 2003)	$s_{Actor\ i} = \frac{1}{3(P_i \times L_i + P_i \times C_i + L_i \times C_i)}$ (5.2.1) Where P_i is Power :the degree an actor has capabilities to impose its needs in relationship $L_i\ is$ legitimacy : socially accepted and expected behaviors $C_i\ is$ urgency : criticality of the actor's claims	We use this measure to calculate the weight of decision makers in interactive decision procedure
2	Network relationship degree	The number of relationships or links which each stakeholders maintain in the network (Grossi, 2003),(Jackson, 2008)	$rd = \frac{\sum_1^N d(s_i)}{N}$ (5.2.2) Where N is the number of actors and d is stakeholder relationship degree	Measuring the stakeholders network structure
	Network density	The number of relationship between stakeholders with respect to total possible number of links (Grossi, 2003),(Jackson, 2008)	$ND = \frac{2R}{N(N-1)}$ (5.2.3) Where N is the number of actors and R is number of present relationship	
4	Centrality	In general this index shows which stakeholders are more important in the network. It reveals degree of involvement of a node in all the network relations(Grossi, 2003), (Hassan, 2009)	$C_{Actor\ i} = \frac{\sum_{j=1}^N (V_{ij}+V_{ji})}{\sum_{i=1}^N \sum_{j=1}^N V_{ij}}$ (5.2.4) Where N is the number of actors V_{ij} is the value proposed by actor i to j and V_{ji} vise versa.	Measuring the cohesiveness of business model and the flexibility of network structure in terms of dependency of stakeholders
5	Information centrality	The average of the information related to the paths linking the actor to the other actors (Grossi, 2003, Stephenson & Zelen ,1989)	$B = S - W + J$ (5.2.5) Where J is unity square matrix, W is relationship matrix and S is diagonal matrix of the sum of the W rows $C = B^{-1}$ $T = \sum_{j=1}^{N} c_{jj}$ $R = \sum_{j=1}^{N} c_{ij}$ $C(i) = \frac{1}{(c_{ii} + (^{(T-2R)}/_{N})}$	Measuring the efficiency of learning and feedbacks in the network

	Storage and parking facility	Dismantler	Pre-shredding	Shredding and recycling facility	Authorities (Accreditation body)	Aircraft manufacturer	EOL enterprise
Storage and parking facility		1	1	1	0	0	0
Dismantler	1		1	1	1	0	0
Pre-shredding	1	1		1	0	0	0
Shredding and recycling facility	1	1	1		0	0	0
Authorities (Accreditation body)	0	1	0	0		0	1
Aircraft manufacturer	0	0	0	0	0		1
EOL enterprise	0	0	0	0	1	1	

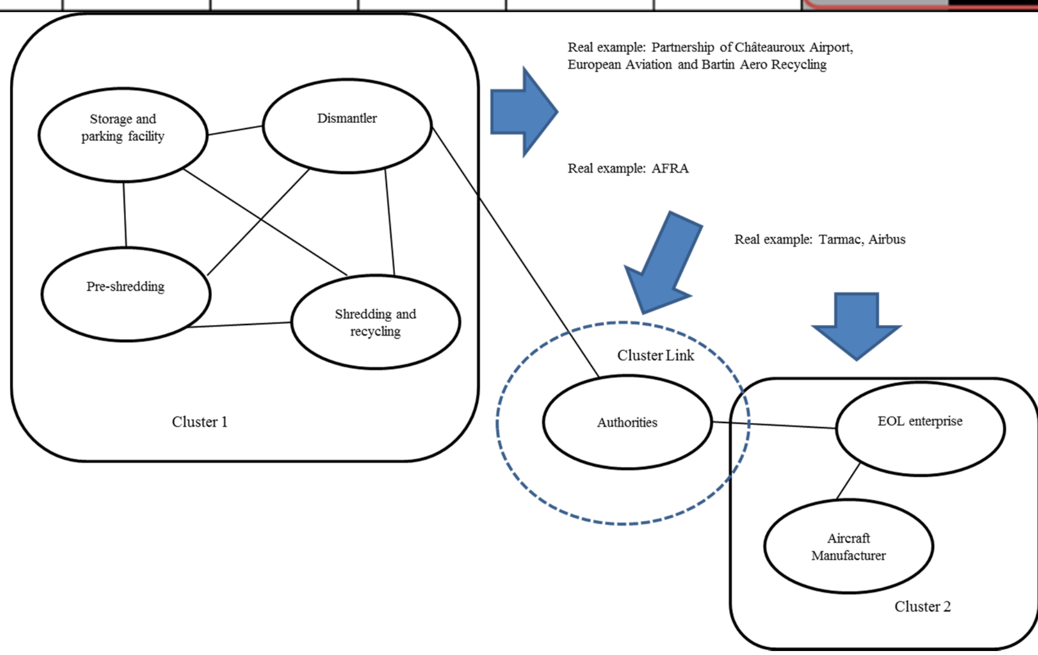


Figure 88 : Dependency structure matrix analysis in the network of EOL aircraft stakeholder's network

5.2.6.2. Management level

In this part, the relevant principles in order to support decisions relating to the management of value loops, proposing an approach to evaluate impacts of changing and uncertain business environment on value loop performances are addressed. The required plans and control to ensure that material flows, recovery channels and value exchange among the stakeholders are organized and meet the objective of the whole recovery network will be covered in this level.

5.2.6.3. Performance measurement

The first performance measurement is cost effectiveness of the whole process. The costs of recycling operation depend on different parameters. Total making of the process or outsourcing some sub-processes can affect the total costs. However, the transportation costs (depending on the mode of transportation) need to be considered. Labour costs are important element in dismantling and disassembling and depend on the skills and experiences of the labour. Moreover, the equipment, technology costs for sorting and material costs need to be considered. The recycling and recovery rate of whole process is another index for performance measurement of the value chain. T

he study (Van Heerden & Curran, 2011) discussed the recyclability and recoverability rate of the EOL aircraft based on Eq. 5.2.6-5.2.7. Which mv is vehicle mass, mTr is non-metalic residue treatment step as recyclable, mTe, non-metallic residue treatment step as energy recovery and mM metal separation.

$$Rcyc = \frac{mM + mTr}{mv} \times 100 \qquad (5.2.6)$$

$$Rcov = \frac{mM + mTr + mTe}{mv} \times 100 \qquad (5.2.7)$$

Environmental and social performance of the process is the next indicator for evaluation of the operation performance. The last indicator for performance measurement is growth and learning across the value chain. As discussed before, appropriate feedbacks in each sub-process of the operation can be valuable for aircraft manufactures for considering in design stage of future aircrafts. Moreover, the growth of the chain in order to act as an infrastructure for recycling in future (like ELV recycling infrastructure) can be the other indicator for evaluation of the whole process.

5.2.6.4. Logistics

The logistics management and its whole value chain management include an integration of demand and supply of materials during EOL aircraft treatment and related decisions regarding planning and operational processes. This step in lean management philosophy is value propositions and delivery phases. Because we need to analyze the value trade-off among the actors in order to provide a balanced and robust value creation framework as well as the realization of the value for stakeholders (see Murman, (2002) and Grossi, (2003)) for more details about the value creation process). Hence, we need to map the flow of materials and identify the value delivery via parts and components recovery and material recovery channels. Identification of the target markets for materials and components is essential step in logistics management because it can determine the demand and supply sides issues. However, in the case of EOL aircrafts, the complexity and challenges associated with material recovery should be considered. According to (Van Heerden & Curran, 201, p.4), “There is no market for the recycled material, but it can be used in other recycling streams of a lower quality, e.g., aircraft aluminum consists of several very specific high-quality alloys. The secondary recycling stream, therefore, also consists of these alloys and to sustain the quality of the original virgin material the different alloys should be separated.” Hence, the available technologies and the economics of recycling material streams should be taken into account. When the recycling or down-cycling are not the feasible options, the energy recovery or landfilling should be considered. The materials flows and all possible recovery channels are shown in Figures 89-92. We supposed that there is one type of EOL aircraft with valuable parts. Figures 89 -91 show the material flow related to the different sub-processes of EOL aircraft treatment which are described in details in previous sections. Each sub process has certain wastes, hazardous material, fluids and other valuable material streams, which should be addressed in sustainable development context.

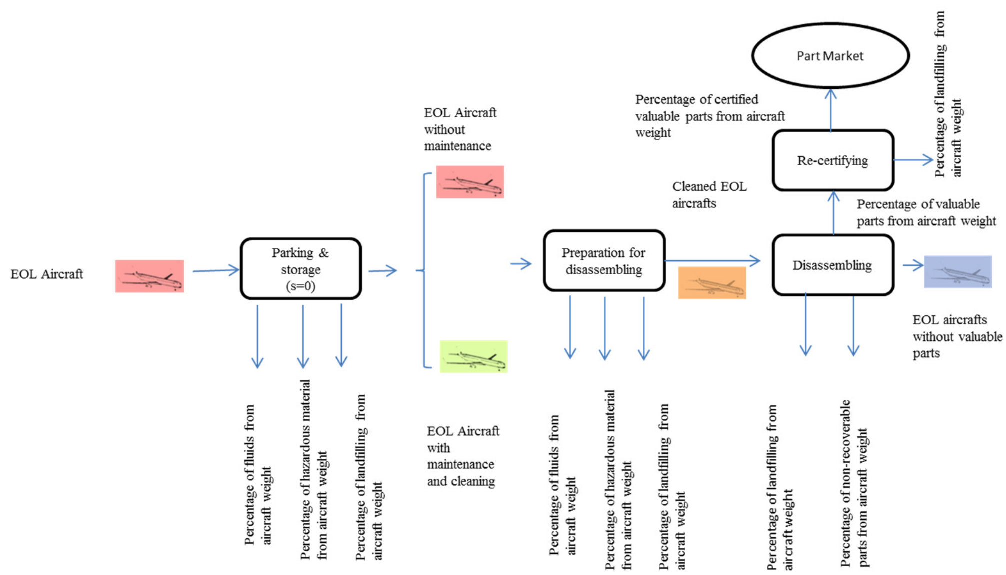


Figure 89 : EOL aircraft treatment material flow (Part A)

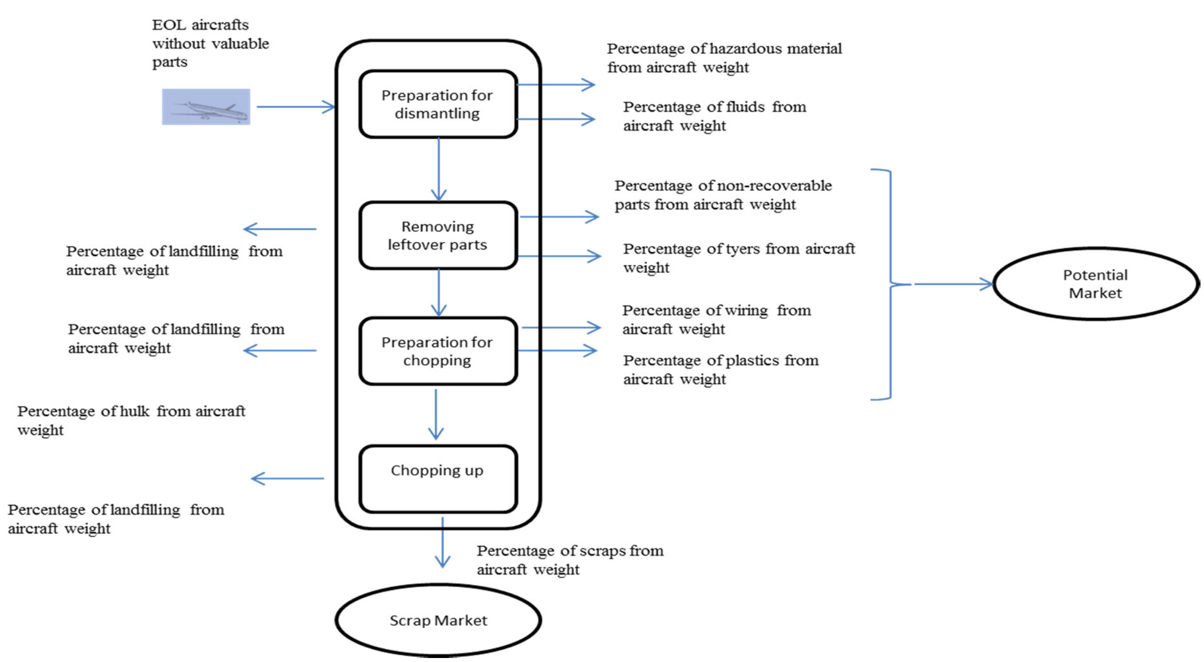


Figure 90 : EOL aircraft treatment material flow (Part B)

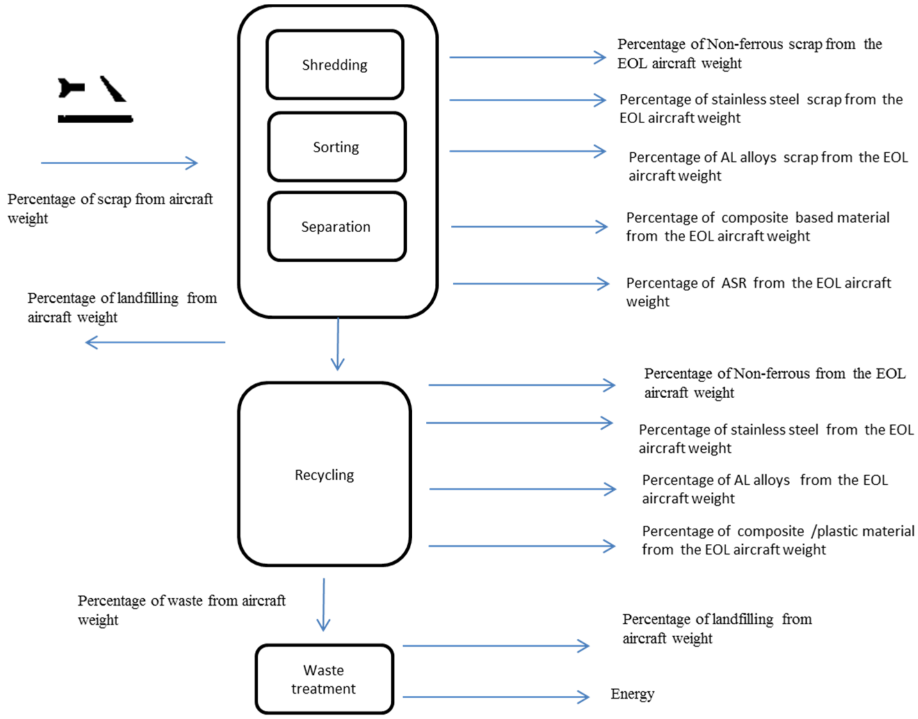


Figure 91 EOL aircraft treatment material flow (Part C)

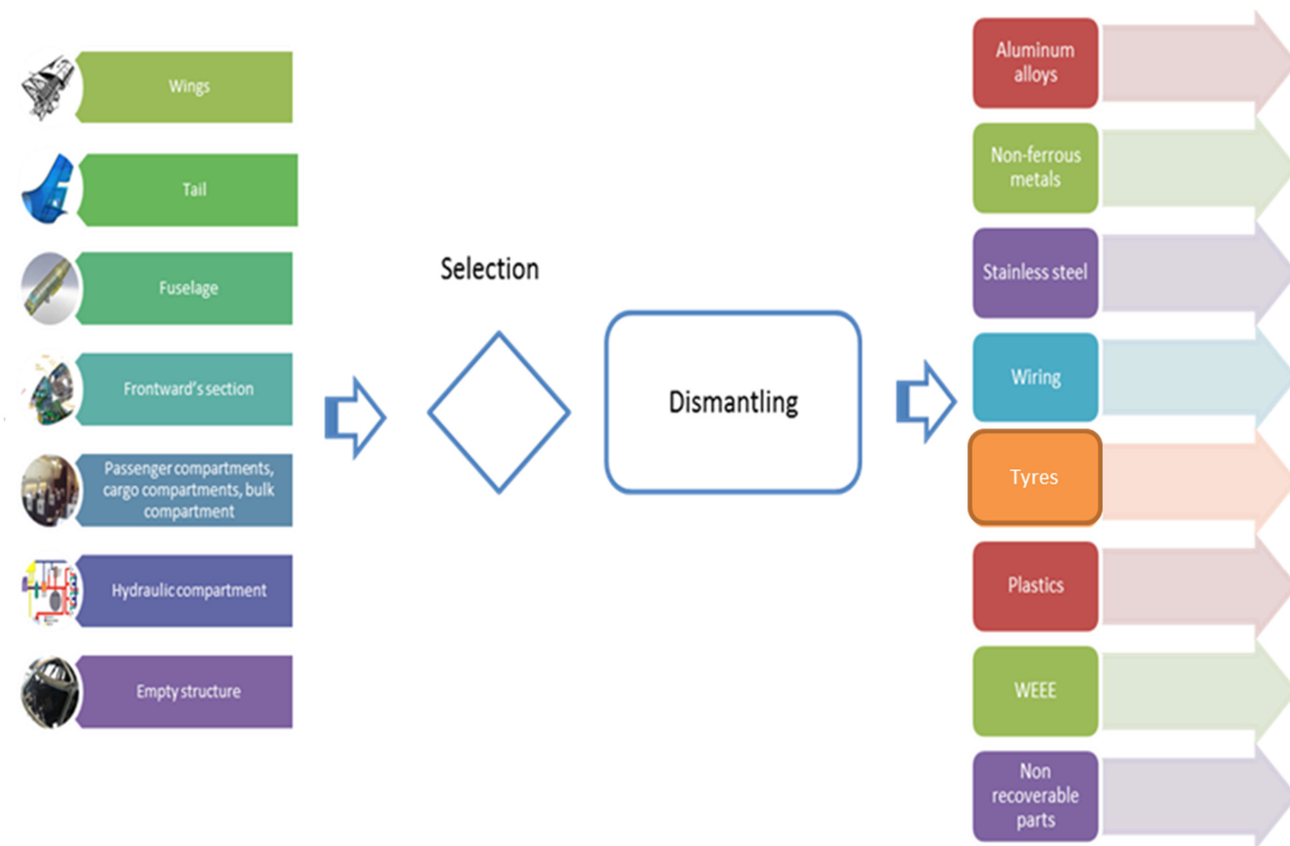


Figure 92 : Recovery channels in EOL aircraft problem

5.2.7. Conclusion

In this paper, we presented a novel holistic optimization framework and multiobjective mathematical model based on sustainable development, lean management and global business environment for EOL aircraft treatment. This framework provides an integrated approach to model strategic and managerial decisions considering global logistics, network structure, dismantling strategies, performance management and management of value chain. This framework is flexible to incorporate the different stakeholders in decision making process via an interactive procedure. To the best of our knowledge, this is the first time that recovery of EOL aircraft is considered based on three aspects of sustainability, lean and Global business. Therefore, this study provides many possible outlooks in this context to enrich the literature of EOL aircrafts as a new aviation industry's challenge and opportunity.

References

AFRA official website retrieved from http://www.afraassociation.org/

Allen, D., & Raynor, M. E. (2004). Preparing for a new global business environment: divided and disorderly or integrated and harmonious? Journal of Business Strategy, 25(5), 16-25.

Bombardier Website http://csr.bombardier.com/en

Cetinkaya, B., Cuthbertson, R., Ewer, G., Klaas-Wissing, T., Piotrowicz, W, & Tyssen, C. (2011). Sustainable Supply Chain Management. Heidelberg, GER: Springer Verlang Berlin Heidelberg.

Das, S. K., & Kaufman, J. G. (2008). Recycling aluminum aerospace alloys. Advanced Materials and Processes, 166(3), 34.

Eppinger, S. D., Whitney, D. E., Smith, R. P., & Gebala, D. A. (1994). A model-based method for organizing tasks in product development. Research in Engineering Design, 6(1), 1-13.

Franz, K., Hörnschemeyer, R., Ewert, A., Fromhold-Eisebith, M., Böckmann, M. G., Schmitt, R., & Reichmuth, J. (2012). Life Cycle Engineering in Preliminary Aircraft Design. In Leveraging Technology for a Sustainable World (pp. 473-478). Springer Berlin Heidelberg.

Grossi, I. (2003). Stakeholder analysis in the context of the lean enterprise (Doctoral dissertation, Massachusetts Institute of Technology).

Hassan, N. R. (2009). Using social network analysis to measure IT-enabled business process performance. Information Systems Management, 26(1), 61-76.

Jackson, M., (2008),"Social and Economic Networks ",Princeton University Press

Keivanpour, S., Ait-Kadi, D., & Mascle, C. (2013-a). Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects, A Research Agenda in Transdisciplinary Context. Journal of Management & Sustainability, 3(3), p76

Keivanpour, S., Mascle, C., & Ait-Kadi, D. (2013-b). Modeling Robustness of Business Ecosystem of End of Life Vehicles Players. Journal of Sustainable Development Studies, 4(1).

Keivanpour, S., Ait Kadi, D., & Mascle, C. (2014-a). Toward a Decision Tool for Eco-Design Strategy Selection of Aircraft Manufacturers Considering Stakeholders Value Network. SAE International Journal of Materials & Manufacturing, 7(1), 73-83.

Keivanpour, S., Kadi, D. A., & Mascle, C. (2014-b). A Conceptual Framework for Value Chain Analysis of Aircraft Recycling in the Context of Sustainable Development Accepted in SAE 2014 Aerospace Manufacturing and Automated Fastening Conference & Exhibition

Latremouille-Viau, J., Baptiste, P., & Mascle, C. (2010). Airframe Dismantling Optimization for Aerospace Aluminum Valorization. In Frontiers of Assembly and Manufacturing (pp. 157-169). Springer Berlin Heidelberg.

Li, P., Dahmus, J., Guldberg, S., Riddervold, H. O., & Kirchain, R. (2011). How much sorting is enough. Journal of Industrial Ecology, 15(5), 743-759.

Lyons, D. I. (2007). A spatial analysis of loop closing among recycling, remanufacturing, and waste treatment firms in Texas. Journal of Industrial Ecology, 11(1), 43-54.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. Academy of management review, 22(4), 853-886.

Murman, E. M. (2002). Lean enterprise value: insights from MIT's lean aerospace initiative. Palgrave Macmillan.

Sainte-Beuve, D. (2012). Évaluation de différentes stratégies de démantèlement de la carcasse d'un avion Master dissertation, École Polytechnique de Montréal).

Siles, C. (2011). Aide à la décision pour la gestion d’un parc d’avions en fin de vie (Master dissertation, École Polytechnique de Montréal).

Van Heerden, D. J , (2005) End-of-Life Aircraft :How to deal with an old aircraft withdrawn from service, Master dissertation(Unpublished)

Van Heerden, D. J., & Curran, R. (2011). Value Extraction from End-of-Life Aircraft. Encyclopedia of Aerospace Engineering. Wiley.

Yang, Y., Boom, R., Irion, B., van Heerden, D. J., Kuiper, P., & de Wit, H. (2012). Recycling of composite materials. Chemical Engineering and Processing: Process Intensification, 51, 53-68.

5.3. End-of-Life Aircraft treatment in the context of Sustainable Development, Lean Management and Global Business (Part B: Optimization model, solution approach and application perspective)

5.3.1. Résumé

Le nombre d'avions en fin de vie augmente sans cesse. La prise en charge des avions en fin de vie compte tenu de leurs impacts environnementaux, sociaux et économiques est devenue un problème émergent dans l'industrie aéronautique pour les années à venir. La partie A du présent document propose une approche holistique des mesures à prendre pour le traitement des avions en fin de vie dans le cadre du développement durable, du Lean management et du Global business. Dans cette partie, un modèle mathématique est développé. Il tient compte de trois objectifs: la minimisation des coûts de réseau logistique, la minimisation de l'impact environnemental et la maximisation des avantages sociaux. Le modèle ainsi proposé ne sera pas seulement un moyen pour aider les décideurs dans leur analyse des réseaux des avions en fin de vie, mais aussi de mettre en évidence les questions importantes liées au recyclage dans un système de création de valeur qui considère toutes les parties prenantes impliquées dans le modèle d'affaires. La proposition d'une solution basée sur l'application conjointe d'une approche interactive des ensembles flous et d'un algorithme génétique permet de résoudre le problème d'optimisation multi-objectif non-linéaire de manière raisonnable. Le point de vue de l'application et des lignes directrices pour l'étude pilote sont également fournis.

Mots-clés: Traitement des avions en fin de vie (EOL), programmation multiobjective, algorithme génétique, approche interactive floue

5.3.2. Abstract

The number of aircrafts at the end of life is continuously increasing. Dealing with retired aircrafts considering the environmental, social and economic impacts is becoming an emerging problem in the aerospace industry in near future. The part A of this paper proposes a holistic approach to End of Life aircraft treatment considering lean management, sustainable development and global business environment. In this part, the mathematical model is developed with three objectives: minimization the costs of logistics network, minimization of environmental impact and maximization of the social benefits. The proposed model will not only aid decision makers in analyzing treatment network of EOL aircraft, but also highlight the significant issues related to recycling in a value creation framework considering all stakeholders involved in the problem and the business model. A solution methodology based on joint application of fuzzy interactive approach and genetic algorithm is also introduced to enable solving the multiobjective nonlinear optimization model in a reasonable manner. The application perspective and guidelines for pilot study are also provided.

Keywords: End of Life (EOL) aircrafts treatment, multiobjective, integrated approach, fuzzy interactive approach

5.3.3. Introduction

According to the airbus forecast by 2032, 10,334 aircraft will be retired (Airbus Report). Dealing with retired aircrafts considering the environmental, social and economic impacts is becoming an emerging problem in the aviation industry in near future. The players involved in the problem wishing to solve this challenge in a systematic way to benefit from the value extracted from the core activities of end of life (EOL) aircraft treatment, decrease the environmental impacts and at the same time maximize the social value to be proficient in the sustainable development context. There are two major challenges facing to solve the problem. First, there is not a rich and developed literature on EOL aircraft treatment. The classical frameworks for logistics networks of product recovery are not adequate to use here. Moreover, the sustainability of whole value chain of treatment considering all involved stakeholders and their expectations and the context of the aviation industry make the problem complex. Second, cost and availability of information is another challenge to tackle such problem. There are few studies that consider the EOL aircraft problem. Van Heerden & Curran, (2011) studied the value extraction from EOL aircrafts. Sainte-Beuve, (2012) evaluates different approaches for skeleton dismantling of the aircraft. Latremouille-Viauet al., (2010) developed a mathematical model in order to optimize the aircraft dismantling process. Siles, (2011) developed a decision tool in order to maximize the profit of dismantling process with respect to the sorting stages. Keivanpour et al., (2013) studies the various aspects of dynamics of EOL aircraft recycling projects. They also proposed a conceptual framework for value chain analysis of EOL aircraft treatment considering sustainability issues. An integrated approach for analyzing the logistic network of EOL aircraft recycling considering the eco-efficiency and profitability is not yet studied in a decision making framework. In this paper, we develop an optimization model to analyze the sustainability of EOL aircraft logistic network.

The main objective of this study is to determine the essential decision elements influencing the Sustainability of key players involved in the problem. The central questions that are to be answered are which business model and treatment process should be selected in order to fulfill the sustainability of the whole network. The rest of the paper is organized as follows: optimization model in ELV context is provided. Next section presents the optimization framework. Following, the mathematical model is presented. The solution approach and application perspective are provided in next section and finally the paper concludes with some remarks and direction for future research.

5.3.4. Optimization models for ELV Recovery

As the research field related to EOL aircraft recycling is absolutely new and there is not a substantial amount of literature, we studied the mathematical models for end of life vehicles (ELV) recovery to bring insight about the modeling and management of this dynamic area. These details aim to identify the key information for more development of this novel research field. The research related to ELV is rich and well developed. According to (Simic, 2013) considering the growing importance of ELV recycling, a substantial number of journal papers have been published in the past ten years. This study classified the related literature into three categories: recycling practices, legislation oriented and remanufacturing and material recycling. According to this article, the modeling approaches can be categorized in life cycle assessment, facility location, production planning (deterministic and stochastic) and material selection. In this section, we focused on that part of literature which covers modeling approaches in recovery logistics and production planning in the context of legislation, global environment or sustainability concerns. Simic & Dimitrijevic, (2012) focused on the production process in a vehicle recycling operation. They presented a tactical production planning problem for vehicle recycling in European Unions (EU) legislation and global business context. They proposed a linear programing model, which optimize storage, recovery, recycling and landfill disposal choices. Simic & Dimitrijevic, (2013) also developed a linear programming model for optimal long-term planning in the EU vehicle recycling factories for securing vehicle hulks, sorting of produced materials, allocation of sorted wastes and metals streams. They considered the trade-offs analysis in order to optimize long term strategies and reducing the risks and uncertainties. Mansour & Zarei, (2008) proposed a multi-period reverse logistics optimization model based on the number, location and the capacity of the collection centers, dismantlers as well as the amount of materials flow between different facilities. Dehghanian &Mansour (2009) proposed a multi-objective programming model for designing recovery network of considering environmental and social impacts for scrap tire case. Dehghanian et al., (2010) also developed an interactive multi-objective decision making approach for designing a sustainable recovery network for scrap tires. Cruz-Rivera & Ertel (2009) addressed an uncapacitated facility location problem which aims to define different aspects of establishing a closed-loop supply chain for the collection of ELV in Mexico. Merkisz-Guranowska (2010) developed a mathematical model for designing of recycling network to satisfy ecological requirements and also efficient management of the whole recovery process. The economic sustainability of the ELV recycling infrastructure is also studied in different research papers. The impact clean vehicle (Boon et al., 2003) and aluminum intensive vehicle (Boon et al., 2000) on US automobile recycling infrastructure also studied via goal programming approach. Keivanpour et al., (2013) proposed a framework for modelling robustness of the business ecosystem of ELV recycling players considering the response to dynamical effects, stability and learning outcomes. They presented how fuzzy rule based model, game theory approach and scenario analysis provides a framework for modeling of ELV recycling dynamics. Synthesis in the literature shows that there is not a holistic approach which addresses lean principle, sustainability and global business simultaneously.

5.3.5. Mathematical model

In this section, the mathematical model for EOL aircraft treatment is proposed. The notations, objective functions and constrains are as follows:

5.3.5.1. The assumptions of the model

a. The EOL aircraft enterprise performs cleaning, preparation, disassembling and removing the parts
b. There is one type of the aircraft with valuable parts
c. Parking site, dismantling and recycling sites have their own waste treatment
d. EOL aircraft enterprise is fully authorized from the owner side and supervises all the process

5.3.5.2. Indices

i: EOL aircraft owner's points

j: EOL aircraft enterprises

k: Parking and storage sites

l: Waste treatment sites

m: Part brokers sites

n: Dismantling sites

o: Recycling sites

mm: Transportation modes

$s0$, $s1, s2$: The stage of sorting

5.3.5.3. Parameters

Fstor_j: The fixed costs of parking and storage if be done by EOL enterprise jth

Fwast_j: The fixed costs of waste treatment if be done by EOL enterprise jth

Fpart_j: The fixed costs of parts sales if be done by EOL enterprise jth

Fdism_j: The fixed costs of dismantling if be done by EOL enterprise jth

Frecy_j: The fixed costs of recycling if be done by EOL enterprise jth

$\mathrm{Fent_j}$: The fixed costs of EOL enterprise jth

$\mathrm{Vstor_j}$: The Variable costs of parking and storage if be done by EOL enterprise jth

$\mathrm{Vwast_j}$: The Variable costs of waste treatment per weight unit if be done by EOL enterprise jth

$\mathrm{Vpart\_sale_j}$: The Variable costs of parts sales per part unit if be done by EOL enterprise jth

$\mathrm{Vdism_j}$: The Variable costs of dismantling per weight unit if be done by EOL enterprise jth

$\mathrm{Vrecy_j}$: The Variable costs of recycling per weight unit if be done by EOL enterprise jth

$\mathrm{Vent_j}$: The Variable costs of EOL enterprise jth

$\mathrm{D\_own\_ent_{ij}}$: Distance between ith EOL aircraft owners point and jth EOL aircraft enterprise

$\mathrm{D\_own\_stor_{ik}}$: Distance between ith EOL aircraft owners point and kth parking and storage sites

$\mathrm{D\_stor\_ent_{kj}}$: Distance between kth Parking and storage sites and jth EOL aircraft enterprise

$\mathrm{D\_ent\_wast_{jl}}$: Distance between jth EOL aircraft enterprise and lth waste treatment sites

$\mathrm{D\_ent\_part_{jm}}$: Distance between jth EOL aircraft enterprise and mth part broker sites

$\mathrm{D\_ent\_dism_{jn}}$: Distance between jth EOL aircraft enterprise and nth dismantling sites

$\mathrm{D\_ent\_recy_{jo}}$: Distance between jth EOL aircraft enterprise and oth recycling sites

C_{tmm}: Transportation costs of a weight unit per distance unit for transportation mode mm

E_{tmm}: Environmental impact of transportation of a weight unit per distance unit for transportation mode mm

C_{outsk} : Outsourcing costs to parking and storage site kth

C_{outsl} : Outsourcing costs to waste treatment site lth

C_{outsm} : Outsourcing costs to part broker site mth

C_{outsn} : Outsourcing costs to dismantling site nth

C_{outso} : Outsourcing costs to recycling site oth

N_i: Number of aircarft in ith EOL aircraft owner point

Ca_stor_k: The maximum potential capacity of kth parking and storage site

Ca_ent_j: The maximum potential capacity of jth EOL aircraft enterprise

Ca_wast_l: The maximum potentialcapacity of lth waste treatment sites

Ca_dism_n: The maximum potential capacity of nth dismanteling sites

Ca_recy_o: The maximum potential capacity of oth Recyclying sites

Ca_part_m: The maximum potential capacity of mth part broker sites

αf_stor_k: The Percentage of fluids from the EOL aircraft weight for parking and storage site k

αf_ent_j: The Percentage of fluids from the EOL aircraft weight for EOL aircraft enterprise j

αf_dism_n: The Percentage of fluids from the EOL aircraft weight for EOL aircraft enterprise n

$\gamma f\_sorting_{s1}$: Percentage of fluids from the EOL aircraft weight if the stage of sorting is changed from 0 to 1

$\gamma f\_sorting_{s2}$: Percentage of fluids from the EOL aircraft weight if the stage of sorting is changed from 1 to 2

αhz_stor_k: The percentage of hazardous materials for parking and storage site k

αhz_ent_j : The percentage of hazardous materials for EOL aircraft enterprise j

$\gamma hz\_sorting_{s1}$: The percentage of hazardous materials if the stage of sorting is changed from 0 to 1

$\gamma hz\_sorting_{s2}$: The percentage of hazardous materials if the stage of sorting is changed from 1 to 2

αhz_dism_n : The percentage of hazardous materials for dismantling site n

αhz_wast_l : The percentage of hazardous materials for waste treatment facility site l

αnf_ent_j: The Percentage of Non-ferrous metal without Al from the EOL aircraft weight for EOL aircraft enterprises *j*

αnf_recy_o: The Percentage of Non-ferrous metal from without Al from the EOL aircraft weight for recycling site o

αnf_dism_n: The Percentage of Non-ferrous metal from the EOL aircraft weight for dismantling site n

αst_ent_j: The Percentage of stainless steel from the EOL aircraft weight for EOL aircraft enterprise *j*

αst_recy_o: The Percentage of stainless steel from the EOL aircraft weight for recycling site o

αst_dism_n: The Percentage of stainless steel from the EOL aircraft weight for dismantling site n

αAl_ent_j: The Percentage of Al alloys from the EOL aircraft weight for EOL aircraft enterprise *j*

αAl_recy_o: The Percentage of Al alloys from the EOL aircraft weight for recycling site o

αAl_dism_n: The Percentage of Al alloys from the EOL aircraft weight for dismantling site n

αvp_ent_j: The percentage of valuable parts from EOL aircraft enterprise j

αvp_dism_n: The percentage of valuable parts from dismantling site n

αnrp_ent_j: The Percentage of non-recoverable parts from the EOL aircraft weight for EOL aircraft enterprise j

$\gamma nrp\_sorting_{s1}$: The percentage of non-recoverable parts from the EOL aircraft weight if the stage of sorting is changed from 0 to 1

$\gamma nrp\_sorting_{s2}$: The percentage of non-recoverable parts from the EOL aircraft weight if the stage of sorting is changed from 1 to 2

αnrp_dism_n: The Percentage of non-recoverable parts from the EOL aircraft weight for dismantling site n

αp_ent_j: The Percentage of plastics from the EOL aircraft weight for EOL aircraft enterprise j

$\gamma p\_sorting_{s1}$: The percentage of plastics from the EOL aircraft weight if the stage of sorting is changed from 0 to 1

$\gamma p\_sorting_{s2}$: The percentage of plastics from the EOL aircraft weight if the stage of sorting is changed from 1 to 2

αp_dism_n: The Percentage of plastics from the EOL aircraft weight for dismantling site n

αp_recy_o: The Percentage of plastics from the EOL aircraft weight for recycling site o

αlf_ent_j: The Percentage of landfilling from the EOL aircraft weight for EOL aircraft enterprises j

$\gamma lf\_sorting_{s1}$: The Percentage of landfilling from the EOL aircraft weight if the stage of sorting is changed from 0 to 1

$\gamma lf\_sorting_{s2}$: The Percentage of landfilling from the EOL aircraft weight if the stage of sorting is changed from 1 to 2

αlf_dism_n: The Percentage of landfilling from the EOL aircraft weight for dismantling site n

αlf_waste_l: The Percentage of landfilling from the EOL aircraft weight for waste treatment facility l

αlf_recy_o: The Percentage of landfilling from the EOL aircraft weight for recycling site o

$\gamma w\_sorting_{s1}$: Percentage of wiring the EOL aircraft weight if the stage of sorting is changed from 0 to 1

$\gamma w\_sorting_{s2}$: Percentage of wiring the EOL aircraft weight if the stage of sorting is changed from 1 to 2

αw_dism_n: The Percentage of wiring the EOL aircraft weight for dismantling site nth

αw_ent_j: The Percentage of wiring the EOL aircraft weight for EOL aircraft site jth

m_m: Percentage of metal materials

m_{tr}:Percentage of non metallic materials

m_{te}: Percentage of materials for energy recovery

R_{cyc}: Recyclability rate

R_{recov}: Recoverability rate

L : Acceptable learning feedbacks

$ECstor_k$: The consumed energy by parking and storage sites kth

$ECwast_l$: The consumed energy by waste treatment siteslth

$ECdism_n$: The consumed energy by dismanteling sites nth

$ECrecy_o$: The consumed energy by Recyclying sites oth

$ECent_j$: The consumed energy by EOL aircraft enterprise jth

$ECents_j$: *The additional* Energy consumbed by *EOL* aircraft enterprise j if it makes the parking and storage by itself

$ECentw_j$: *The additional* Energy consumbed by *EOL* aircraft enterprise if it makes the waste treatment

$ECentd_j$: *The additional* Energy consumbed by *EOL* aircraft enterprise if it makes dismantling by itself

$ECentr_j$: *The additional* Energy consumbed by *EOL* aircraft enterprise if it makes recycling by itself

$EIstor_k$: *The* Enviornmental *impact of* parking and storage sites kth

$EIent_j$: *The* Enviornmental *impact of EOL* aircraft enterprise jth

$EIents_j$: *The additional* Enviornmental *impact* of EOL aircraft enterprise j *if* it makes the parking and storage by itself

$EIentp_j$: *The additional* Enviornmental *impact of EOL aircraft enterprise j if* it makes the part sales by itself

$EIentw_j$: *The additional* Enviornmental *impact of EOL aircraft enterprise if* it makes the waste treatment

$EIentd_j$: *The additional* Enviornmental *impact of EOL aircraft enterprise if* it makes dismantling by itself

$EIentr_j$: *The additional* Enviornmental *impact of EOL aircraft enterprise if* it makes recycling by itself

$EIwast_l$: *The*Enviornmental *impact of waste treatment sites lth*

$EIpart_m$: *The* Enviornmental *impact of part broker site mth*

$EIdism_n$: *The* Enviornmental *impact of dismanteling sites nth*

$EIrecy_o$: *The* Enviornmental *impact of recyclying sites oth*

$Emstor_k$: *The employment score of parking and storage sites kth*

$Ement_j$: *The employment score of EOL aircraft enterprise jth*

$Ements_j$: $The\ additional\ \ employment\ score\ of\ EOL\ aircraft\ enterprise$

if it makes the parking and storage by itself

$Ementw_j$: $The\ additional\ employment\ score\ of\ EOL\ aircraft\ enterprise$

if it makes the waste treatment

$Ementp_j$: $The\ additional\ employment\ score\ of\ EOL\ aircraft\ enterprise$

if it makes parts sales by itself

$Ementd_j$: $The\ additional\ employment\ score\ of\ EOL\ aircraft\ enterprise$

if it makes dismantling by itself

$Ementr_j$: $The\ additional\ employment\ score\ of\ EOL\ aircraft\ enterprise$

if it makes recycling by itself

$Emwast_l$: $The\ employment\ score\ of\ waste\ treatment\ sites\ lth$

$Empart_m$: $The\ employment\ score\ of\ part\ broker\ site\ mth$

$Emdism_n$: $The\ employment\ score\ of\ dismanteling\ sites nth$

$Emrecy_o$: $The\ employment\ score\ of\ Recyclying\ sites oth$

$Rwstor_k$: $The\ risk\ of\ working\ condition\ of$ parking and storage sites kth

$Rwentj$: $The\ risk\ of\ working\ condition\ of\ EOL\ aircraft\ enterprisejth$

$Rwents_j$: $The\ additional\ \ risk\ of\ working\ condition\ of EOL\ aircraft\ enterprise$

if it makes the parking and storage by itself

$Rwentw_j$: $The\ additional\ \ risk\ of\ working\ condition\ \ of\ EOL\ aircraft\ enterprise$

if it makes the waste treatment

$Rwentd_j$: $The\ additional\ risk\ of\ working\ condition\ \ of\ EOL\ aircraft\ enterprise$

if it makes dismantling by itself

$Rwentr_j$: $The\ additional\ risk\ of\ working\ condition\ \ of\ EOL\ aircraft\ enterprise$

if it makes recycling by itself

$Rwwast_l$: $The\ risk\ of\ working\ condition\ of\ waste\ treatment\ sites\ lth$

$Rwdism_n$: $The\ risk\ of\ working\ condition\ of\ dismanteling\ sites\ nth$

$Rwrecy_o$: $The\ risk\ of\ working\ condition\ of\ Recyclying\ sites\ oth$

$Lstor_k$: *The Learning (valuable feedback for design) score of parking and storage site kth*

$Lents_j$: *The Learning (valuable feedback for design)score of EOL aircraft enterprise if* it makes the parking and storage by itself

$Lentw_j$: *The Learning (valuable feedback for design)score of EOL aircrat enterprise if* it makes the waste treatment

$Lentp_j$: *The Learning (valuable feedback for design)score of EOL aircraft enterprise if* it makes parts sales by itself

$Lentd_j$: *The Learning (valuable feedback for design)score of EOL aircraft enterprise if* it makes dismantling by itself

$Lentr_j$: *The Learning (valuable feedback for design)score of EOL aircraft enterprise if* it makes recycling by itself

$Lwast_l$: *The Learning (valuable feedback for design) score of waste treatment site lth*

$Ldism_n$: *Learning (valuable feedback for design) score dismanteling site nth*

$Lrecy_o$: Learning (valuable feedback for design) score of Recyclying sites oth

$Lent_j$: Learning (valuable feedback for design) score of EOL aircraft enterprise jth

$Lpart_m$: *The Learning (valuable feedback for design) score of part broker site mth*

$Clstor_k$: The cost of learning (valuable feedback for design) of parking and storage site *kth*

$Clwast_l$: The cost of Learning (valuable feedback for design) score of waste treatment sites *lth*

$Cldism_n$: The cost of Learning (valuable feedback for design) of dismanteling sites *nth*

$Clrecy_o$: The cost of Learning (valuable feedback for design) of Recyclying sites *oth*

$\mathrm{Clent_j}$: The cost of Learning (valuable feedback for design) of EOL aircraft enterprise jth

$\mathrm{Clpart_m}$: The cost of Learning (valuable feedback for design) of $part\ brokersite\ mth$

C_{lf}: Landfill costs in site

Tx: Tax in site

L_r: $additional\ Local\ regulation\ cost$ *(The responsible authority)*

$Rch_{s0,s1}$: Human recourses (hours) for status change between stage 0 and 1

$Rch_{s1,s2}$: Human recourses (hours) for status change between stage 1 and 2

$Em_{s1,s2}$: $The\ employment\ score\ of$ status change between stage 1 and 2

$CRch$: Human resource price

$CST_{s0,s1}$: The sorting technique costs for status change between stage 0 and 1

$CST_{s1,s2}$: The sorting technique costs for status change between stage 1 and 2

$EIST_{s0,s1}$: The environmental impact for status change between stage 0 and 1

$EIST_{s1,s2}$: The environmental impact for status change between stage 1 and 2

$Rw_{s0,s1}$: $The\ risk\ of\ working\ condition\ of\ EOL\ aircraft\ enterprise$ *if* the stage of sorting is changed from 0 to 1

$Rw_{s1,s2}$: $The\ risk\ of\ working\ condition\ of\ EOL\ aircraft\ enterprise$ if the stage of sorting is changed from 1 to 2

5.3.5.4. Decision Variable

$Xstor_k$: A binary variable which is equal to 1 if the parking and storage site kth is selected and 0 otherwise

$Xent_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth is selected and 0 otherwise

$Xents_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth makes the parking and storage by itself and 0 otherwise

$Xentw_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth makes the waste treatment by itself and 0 otherwise

$Xentp_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth is makes part sale by itself and 0 otherwise

$Xentdism_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth makes dismantling by itself and 0 otherwise

$Xentrecy_j$: A binary variable which is equal to 1 if the EOL aircraft enterprises jth makes recycling by itself and 0 otherwise

$Xwast_l$: A binary variable which is equal to 1 if the Waste treatment sites lth is selected and 0 otherwise

$Xpart_m$: A binary variable which is equal to 1 if the Part brokers sites mth is selected and 0 otherwise

$Xdism_n$: A binary variable which is equal to 1 if the Dismantling sites nth is selected and 0 otherwise

$Xrecy_o$: A binary variable which is equal to 1 if the Recycling sites oth is selected and 0 otherwise

$D\_own\_ent_{ij}$: Distance between ith EOL aircraft owners point and jth EOL aircraft enterprise

$D\_own\_stor_{ik}$: Distance between ith EOL aircraft owners point and kth parking and storage sites

$D\_stor\_ent_{kj}$: Distance between kth Parking and storage sites and jth EOL aircraft enterprise

$D\_ent\_wast_{jl}$: Distance between jth EOL aircraft enterprise and lth waste treatment sites

$D\_ent\_part_{jm}$: Distance between jth EOL aircraft enterprise and mth part broker sites

$D\_ent\_dism_{jn}$: Distance between jth EOL aircraft enterprise and nth dismantling sites

$D\_ent\_recy_{jo}$: Distance between jth EOL aircraft enterprise and oth recycling sites

$Y\_own\_ent_{ij}$: Amount of mass transported from ith EOL aircraft owners point to jth EOL aircraft enterprise

$Y\_own\_stor_{ik}$: Amount of mass transported from ith EOL aircraft owners point to kth Parking and storage sites

$Y\_stor\_ent_{kj}$: Amount of mass transported from kth Parking and storage sites to jth EOL aircraft enterprise

$Y\_ent\_wast_{jl}$: Amount of mass transported from jth EOL aircraft enterprise to lth waste treatment site

$Y\_ent\_part_{jm}$: Amount of mass transported from jth EOL aircraft enterprise to mth part broker site

$Y\_ent\_dism_{jn}$: Amount of mass transported from jth EOL aircraft enterprise to nth dismantling site

$Y\_ent\_recy_{jo}$: Amount of mass transported from jth EOL aircraft enterprise to oth recycling site

SORTING

− *STATUSs*: A binary variable which is equal to 1 if the EOL aircarft change in s sorting stages and 0 otherwise

v_{entsj}: Capacity for parking and storage of EOL enterprise jth

v_{entwj}: Capacity for waste treatment of EOL enterprise jth

v_{entpj}: Capacity for part sale of EOL enterprise jth

v_{entdj}: Capacity for dismantling of EOL enterprise jth

v_{entrj}: Capacity for Recycling of EOL enterprise jth

v_{entj}: Capacity for of EOL enterprise jth

5.3.5.5. Objectives

Minimization of costs

$$\sum_j Xents_j(\mathrm{Fstor_j} + \mathrm{Vstor_j} v_{entsj}) + \sum_j Xentw_j(\mathrm{Fwast_j} + \mathrm{Vwast_j} v_{entwj})$$

$$+ \sum_j Xentp_j(\mathrm{Fpart_j} + \mathrm{Vpart\_sale_j} v_{entpj})$$

$$+ \sum_j Xentdism_j(\mathrm{Fdism_j} + \mathrm{Vdism_j} v_{entdj})$$

$$+ \sum_j Xentrecy_j\left(\mathrm{Frecy_j} + \mathrm{Vrecy} v_{entrj}\right)$$

$$+ \sum_j Xent_j\left(\mathrm{Fent_j} + \mathrm{Vent_j} v_{entj}\right)$$

$$+ \sum_s (SORTING - STATUSs \times (CST_s + Rch_s \times CRch))$$

$$+ \sum_i \sum_k Y\_\mathrm{own\_stor}_{ik} Xstor_k\{C_{outsk} + Txk + Lrk\}$$

$$+ \sum_j \sum_l Y\_\mathrm{ent\_wast}_{jl} Xwast_l\{C_{outsl} + Tx + Lrl + Cdl\}$$

$$+ \sum_j \sum_m Y\_\mathrm{ent\_part}_{jm} Xpart_m\{C_{outsm} + Txm + Lrm\}$$

$$+ \sum_j \sum_n Y\_\mathrm{ent\_dism}\, Xdism_n\{C_{outsn} + Txn + Lrn + Cdn\}$$

$$+ \sum_j Y\_\mathrm{ent\_recy}\, Xrecy_o\{C_{outso} + Txo + Lro + Cdo\}$$

$$+\sum_{i}\sum_{j}\sum_{mm} Y\_own\_ent_{ij}\mathrm{D\_own\_ent_{ij}}C_{tmm}$$

$$+\sum_{i}\sum_{k}\sum_{mm} Y\_\mathrm{own\_stor}_{ik}\mathrm{D\_own\_stor_{ik}}C_{tmm}$$

$$+\sum_{k}\sum_{j}\sum_{mm} Y\_\mathrm{stor\_ent}_{kj}\mathrm{D\_stor\_ent_{kj}}C_{tmm}$$

$$+\sum_{j}\sum_{l}\sum_{mm} Y\_\mathrm{ent\_wast}_{jl}\mathrm{D\_ent\_wast_{jl}}C_{tmm}$$

$$+\sum_{j}\sum_{m}\sum_{mm} Y\_\mathrm{ent\_part}_{jm}\mathrm{D\_ent\_part_{jm}}C_{tmm}$$

$$+\sum_{j}\sum_{n}\sum_{mm} Y\_\mathrm{ent\_dism}_{jn}\mathrm{D\_ent\_dism_{jn}}C_{tmm}$$

$$+\sum_{j}\sum_{o}\sum_{mm} Y\_\mathrm{ent\_recy}_{jo}\mathrm{D\_ent\_recy_{jo}}C_{tmm} \qquad (5.3.1)$$

Minimization of Environmental impacts

$$+\sum_{i}\sum_{j}\sum_{mm} Y\_own\_ent_{ij}\mathrm{D\_own\_ent_{ij}}E_{tmm}$$

$$+\sum_{i}\sum_{k}\sum_{mm} Y\_\mathrm{own\_stor}_{ik}\mathrm{D\_own\_stor_{ik}}E_{tmm}$$

$$+\sum_{k}\sum_{j}\sum_{mm} Y\_\mathrm{stor\_ent}_{kj}\mathrm{D\_stor\_ent_{kj}}E_{tmm}$$

$$+\sum_{j}\sum_{l}\sum_{mm} Y\_\mathrm{ent\_wast}_{jl}\mathrm{D\_ent\_wast_{jl}}E_{tmm}$$

$$+\sum_{j}\sum_{m}\sum_{mm} Y\_\mathrm{ent\_part}_{jm}\mathrm{D\_ent\_part_{jm}}E_{tmm}$$

$$+\sum_{j}\sum_{n}\sum_{mm} Y\_\mathrm{ent\_dism}_{jn}\mathrm{E\_ent\_dism_{jn}}C_{tmm}$$

$$+\sum_{j}\sum_{o}\sum_{mm} Y\_\mathrm{ent\_recy}_{jo}\mathrm{D\_ent\_recy_{jo}}E_{tmm}$$

$$+\sum_{k} Xstor_k\{EIstor_k + ECstor_k\} + \sum_{j} Xent_j\{EIent_j + ECent_j\}$$

$$+\sum_{j} Xents_j\{EIents_j + ECents_j\}$$

$$+\sum_{j} Xentw_j\{EIentw_j + ECentw_j\}$$

$$+\sum_{j} Xentdism_j\{EIentd_j + ECentd_j\}$$

$$+\sum_{j} Xentrecy_j\{EIentr_j + ECentr_j\} + \sum_{j} Xentp_j\{EIentp_j\}$$

$$+\sum_{l} Xwast_l\{EIwast_l + ECwast_l\} + \sum_{m} Xpart_m\{EIpart_m\}$$

$$+\sum_{n} Xdism_n\{EIdism_n + ECdism_n\}$$

$$+\sum_{o} Xrecy_o\{EIrecy_o + ECrecy_o\}$$

$$+\sum_{s} (SORTING - STATUSs \times EIST_s)$$

$$+\sum_{j,k,n,l} (\alpha hz\_ent_j + \alpha hz\_stor_k + \alpha hz\_dism_n + \alpha hz\_wast_l)$$

$$+ \sum\nolimits_{s} SORTING$$

$$- STATUSs(\gamma hz\_sorting_s) \qquad (5.3.2)$$

Maximization of social benefits

$$\sum_{k} Xstor_k Emstor_k + \sum_{j} Xent_j Ement_j$$
$$+ \sum_{j} Xents_j Ements_j + \sum_{j} Xentw_j Ementw_j$$
$$+ \sum_{j} Xentp_j Ementp_j + \sum_{j} Xentdism_j Emdism_n$$
$$+ \sum_{j} Xentrecy_j Ementr_j + \sum_{l} Xwast_l Emwast_l$$
$$+ \sum_{m} Xpart_m Empart_m + \sum_{n} Xdism_n Emdism_n$$
$$+ \sum_{o} Xrecy_o Emrecy_o$$
$$\sum_{k} Xstor_k Rwstor_k + \sum_{j} Xent_j Rwentj$$
$$+ \sum_{j} Xents_j Rwents_j + \sum_{j} Xentw_j Rwentw_j$$
$$+ \sum_{j} Xentdism_j Rwentd_j + \sum_{l} Xentrecy_j Rwentr_j$$
$$+ \sum_{m} Xwast_l Rwwast_l + \sum_{n} Xdism_n Rwdism_n$$
$$+ \sum_{o} Xrecy_o Rwrecy_o$$
$$+ \sum_s (SORTING - STATUSs \times (Em_s + RW_s)) \quad (5.3.3)$$

5.3.5.6. Constrains

All the EOL aircraft should be collected from owner points

$$\sum_{j,k} Y\_own\_ent_{ij} + Y\_\mathrm{own\_stor}_{ik} = \mathrm{N_i} \quad \forall i \quad (5.3.4)$$

Capacity

$Y\_\text{own\_stor}_{ik} \leq \text{Ca\_stor}_\text{k} \quad \forall k, i$ (5.3.5)

$Y\_\text{ent\_wast}_{jl} \leq Ca\_wast_l \quad \forall j, l$ (5.3.6)

$Y\_\text{ent\_part}_{jm} \leq Ca\_part_m \quad \forall j, m$ (5.3.7)

$Ca\_dism_n \leq Ca\_dism_n \quad \forall j, n$ (5.3.8)

$Y\_\text{ent\_recy}_{jo} \leq Ca\_recy_o \quad \forall j, o$ (5.3.9)

$Y\_own\_ent_{ij} \leq v_{entsj} \quad \forall i, j$ (5.3.10)

$Y\_\text{stor\_ent}_{kj} \leq v_{entj} \quad \forall k, j$ (5.3.11)

$Y\_\text{ent\_wast}_{jl} \leq v_{entwj} \quad \forall j, l$ (5.3.12)

$Y\_\text{ent\_part}_{jm} \leq v_{entpj} \quad \forall j, m$ (5.3.13)

$Y\_\text{ent\_dism}_{jn} \leq v_{entdj} \quad \forall j, n$ (5.3.14)

$Y\_\text{ent\_recy}_{jo} \leq v_{entrj} \quad \forall j, o$ (5.3.15)

$f + mt + p + nm + np + lf \geq Rcov$ (5.3.16)

$f + mt + p + nm + np \geq Rcyc$ (5.3.17)

$where$

Fluids

$f = \sum_{k,j,n} Xstor_k \alpha f\_stor_k +, Xent_j \alpha f\_ent_j + Xdism_n \alpha f\_dism_n +$
$\sum_s SORTING - STATUSs\gamma f\_sorting_{s1}$ (5.3.18)

Metals

$mt = \sum_{j,n,o} Xent_j \alpha Al\_ent_j + Xdism_n \alpha Al\_dism_n +$
$Xrecy_o\ \alpha Al\_recy_o + \sum_{j,n,o} Xent_j \alpha st\_ent_j + Xdism_n \alpha st\_dism_n +$
$Xrecy_o \alpha st\_recy_o + \sum_{j,n,o} Xent_j\ \alpha nf\_ent_j + Xdism_n \alpha nf\_dism_n +$
$Xrecy_o \alpha nf\_recy_o$ (5.3.19)

Valuable parts

$p = \sum_{j,n} Xent_j \alpha vp\_ent_j + Xdism_n \alpha vp\_dism_n$ (5.3.20)

Non metals

$nm = \sum_{j,n} Xent_j \alpha w\_ent_j + Xdism_n \alpha w\_dism_n + \sum_s SORTING - STATUSs\gamma w\_sorting_s + \sum_{j,n,o} Xent_j \alpha p\_ent_j + Xdism_n \alpha p\_dism_n + Xrecy_o \alpha p\_recy_o + \sum_s SORTING - STATUSs\gamma p\_sorting_s$ (5.3.21)

Non recoverable parts

$np = \sum_{j,n} Xent_j \alpha nrp\_ent_j + Xdism_n \alpha nrp\_dism_n + \sum_s SORTING - STATUSs\gamma nrp\_sorting_s$ (5.3.22)

Landfill

$lf = \sum_{j,n,o,l} Xent_j \alpha lf\_ent_j + Xdism_n \alpha lf\_dism_n + Xwast_l \alpha lf\_waste_l + Xrecy_o \alpha lf\_recy_o + \sum_s SORTING - STATUSs\gamma lf\_sorting_s$ (5.3.23)

$$\sum_k Xstor_k Lstor_k + \sum_j Xent_j \mathrm{Lent_j} + \sum_j Xents_j Lents_j + \sum_j Xentw_j Lentw_j + \sum_j Xentp_j Lentp_j + \sum_j Xentdism_j Lentd_j + \sum_j Xentrecy_j Lentr_j + \sum_l Xwast_l Lwast_l + \sum_m Xpart_m Lpart_m + \sum_n Xdism_n Ldism_n + \sum_o Xrecy_o \mathrm{Lrecy_o} \geq L \quad (5.3.24)$$

$\sum_{k,j,l,m,n,o} Xstor_k, Xent_j, Xwast_l, Xpart_m, Xdism_n, Xrecy_o = 1$
(25)

All Variables are ≥ 0 *and* Binary Variable 0 or 1 (5.3.26)

The objective function (5.3.1) minimizes the total cost including the costs of different sub process and outsourcing, dismantling strategy and transportation. Objective function (5.3.2) minimizes the environmental impacts of different sub process, outsourcing and transportation and hazardous materials. Objective function (5.3.3) maximizes the social benefit including the social impact of sub process, outsourcing and dismantling strategy. Constraint (5.3.4) ensures that All the EOL aircraft should be collected from owner points. Constrains (5.3.5)-(5.3.15) are capacity constraints. Constraints (5.3.16), (5.3.17) and (5.3.24) control the performance measurements regarding recyclability, recoverability and learning. Equations (5.3.18-5.3.23) show the flow of material distribution through treatment network including fluid, metal, valuable parts, non-metal, non-recoverable parts and wastes. Constrain (5.3.25) ensures that among candidates for each service, only one enterprise should be selected. And finally, constraint (5.3.26) enforces the binary and non-negativity restrictions on decision variables.

5.3.5.7. Network analysis

The network analysis of the resulted logistic network is performed based on the indicators described in details in Part A of the paper. The relationship matrix will be constructed based on the result of optimization model and the actual relationship among the actors. Table 26 shows the relationship matrix. It should be noted that in the mathematical model, we didn't considered the material flows among dismantlers, recyclers and waste treatment facilities. However, these parties can establish joint cooperation. Moreover, the aircraft manufacturer, authorities, media and the other partners are not considered in the mathematical model. Though, for a complete network analysis, these actors also need to be added to the matrix.

The type of the relationship is also essential in the network analysis. For example, three types of relationship are defined in this study to determine the optimum network structure based on the strengths of connection among the actors. The first type of the relations named R_1 , which is the information sharing between two actors. This information sharing can be achieved due the regular meetings or the organized reports. The second type called R_2 is a service contract form between the actors and the third type, R_3, is more stronger relationship like a joint venture agreement or strategic alliance between actors. For measuring the stakeholder's network structure, we used Eq. 5.3.27, 5.3.28 (see part A of the paper for more explanation about these relations). The intensity of the relationships between stakeholders is revealed in this part. The actor which needs to regularly communicate with other actors (such as EOL enterprise) has a high network relationship degree. The network density also shows the structural complexity of the network. The density of subgroups can also be calculated. For example, the density of the relationship among (dismantler, part broker, and recycler and waste treatment actors) shows the need for a great coordination among these actors. The analysis of the centrality (Eq. 5.3.29, 5.3.30) leads to information related to cohesiveness of the business model and efficiency of linking paths. The more central actor which acts as a hub and governance policy can be defined based on this analysis. The value matrix is shown in Table 27. The functional characteristic of the actor's network will be obtained by Eq.5.3.30. With this indicator we find the critical relationship in the network. If these relationships get unsettled the functionality of the network will be affected.

$$rd = \frac{\sum_1^N d(s_i)}{N} \quad (5.3.27)$$

Where N is the number of actors and d is stakeholder relationship degree

$$ND = \frac{2R}{N(N-1)} \quad (5.3.28)$$

Where N is the number of actors and R is number of present relationship

$$C_{Actor\ i} = \frac{\sum_{j=1}^N (V_{ij}+V_{ji})}{\sum_{i=1}^N \sum_{j=1}^N V_{ij}} \quad (5.3.29)$$

Where N is the number of actors V_{ij} is the value proposed by actor i to j and V_{ji} vise versa.

$$C(i) = \frac{1}{(c_{ii}+(^{(T-2R)}/_{N})} \quad (5.3.30)$$

$$B = S - W + J \quad (5.3.31)$$

Where J is unity square matrix, W is relationship matrix and S is diagonal matrix of the sum of the W rows

$$C = B^{-1} \quad (5.3.32)$$

$$T = \sum_{j=1}^N c_{jj} \quad (5.3.33)$$

$$R = \sum_{j=1}^N c_{ij} \quad (5.3.34)$$

Table 26 : The Relationship matrix

	EOL aircraft owner (Actor 1)	EOL aircraft enterprise (Actor 2)	Parking and storage site (Actor 3)	Part brokers site (Actor 4)	Dismantling site (Actor 5)	Recycling site (Actor 6)	Waste treatment site (Actor 7)
EOL aircraft owner (Actor 1)	-	$Xents_j$	$Xstor_k$	-	-	-	-
EOL aircraft enterprise (Actor 2)	$Xents_j$	-	$Xstor_k$	$Xpart_m$	$Xdism_n$	$Xrecy_o$	$Xwast_l$
Parking and storage site (Actor 3)	$Xstor_k$	$Xstor_k$	-	-	-	-	-
Part brokers site (Actor 4)	-	$Xpart_m$	-	-	-	-	-
Dismantling site (Actor 5)	-	$Xdism_n$	-	-	-	-	-
Recycling site (Actor 6)	-	$Xrecy_o$	-	-	-	-	-
Waste treatment site (Actor 7)	-	$Xwast_l$	-	-	-	-	-

Table 27 : The value matrix

	EOL aircraft owner (Actor 1)	EOL aircraft enterprise (Actor 2)	Parking and storage site (Actor 3)	Part brokers site (Actor 4)	Dismantling site (Actor 5)	Recycling site (Actor 6)	Waste treatment site (Actor 7)
EOL aircraft owner (Actor 1)	-	vij If $Xents_j = 1$	vik If $Xstor_k = 1$	-	-	-	-
EOL aircraft enterprise (Actor 2)	vji If $Xents_j = 1$	-	vjk If $Xstor_k = 1$	vjm If $Xpart_m = 1$	vjn If $Xdism_n = 1$	vjo If $Xrecy_o = 1$	vjl If $Xwast_l = 1$
Parking and storage site (Actor 3)	vki If $Xstor_k = 1$	vkj If $Xstor_k = 1$	-	-	-	-	-
Part brokers site (Actor 4)	-	vmj If $Xpart_m = 1$	-	-	-	-	-
Dismantling site (Actor 5)	-	vnj If $Xdism_n = 1$	-	-	-	-	-
Recycling site (Actor 6)	-	voj If $Xrecy_o = 1$	-	-	-	-	-
Waste treatment site (Actor 7)	-	vlj If $Xwast_l = 1$	-	-	-	-	-

5.3.6. Solution approach

Considering objective functions and constrains, we are facing with a multiple objective mixed integer non-linear programming model. There are different approaches for solving these types of problems. However, the stability in such problems is key element. Moreover, the nature of data, uncertainty in parameters and the flexibility of decision makers for finding the Pareto optimal solution need to be considered. In this section, we have an overview over the related literature for solving these problems and propose a methodology for solving. We utilize fuzzy programming approach, interactive decision making principles and genetic algorithm for solving the problem.

5.3.6.1. The proposed approach

Generally, a multi-objective optimization model could be modeled as follows:

Minimize $f(x) = \{f_1(x), f_2(x), f_3(x), \dots, f_k(x)\}\ \forall k \in K$ (5.3.35)

Subject to $h_i(x) = 0, \forall i \in I$

$g_j(x) \leq 0, \forall j \in J$

$x \in X$

Where $f_1(X), f_2(X), f_3(X), \dots, f_k(X)$ are objective functions. $h_i(X)$ and $g_j(X)$ are constraint functions and X is decesion space and x is decision vector. In the case of nonlinear model x is an n dimensional vector of decision variables ($x \in \varphi^n$).

The Pareto optimal solution is defined as a vector X^* if there exists no feasible vector X which decreases objective function without an increase in at least one objective.

In the other word if $f_i(X) \leq f_i(X^*) \rightarrow f_j(X) \geq f_i(X^*)$

This trade-off solution which usually belongs to a set of optimal solutions must be selected based on the preference of decision makers.

As we explained in the previous sub-section, we face a problem with different kind of uncertainty including lack of knowledge or uncertainty in flexibility of setting goals. Fuzzy set theory proposed by Zadeh(Negoita et al.,1978) provides a basis for dealing with these types of uncertainties.

A fuzzy number is defined with a membership function. For example if $\widetilde{A}$ is a fuzzy number, triangular membership function of $\widetilde{A}$ is defined as follows (Figure 93):

$$\mu_{A(x)} = \begin{cases} \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & \text{otherwise} \end{cases} \quad (5.3.36)$$

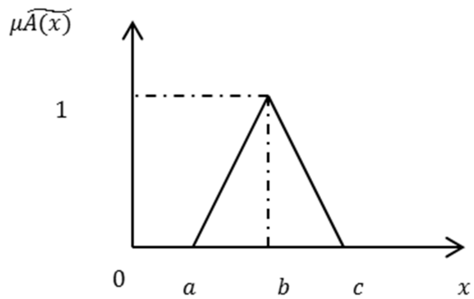


Figure 93 : Triangular membership function of $\widetilde{A}$

Hence the problem (Eq. 5.3.35) could be written as Fuzzy format as follows:

$$\text{Minimize } \widetilde{f(x)} = \{\widetilde{f_1(x)}, \widetilde{f_2(x)}, \widetilde{f_3(x)}, \dots, \widetilde{f_k(Xx)}\}\ \forall k \in K \quad (5.3.37)$$

Subject to $\widetilde{h_i(x)} = 0, \forall i \in I$

$\widetilde{g_j(x)} \le 0, \forall j \in J$

$x \in X$

There are several approaches for solving these problems. In this part, we have an overview over the solution methodologies for solving these types of problem and then propose our algorithm for solving the problem. For solving a fuzzy multi-objective optimization model, we need to transfer the fuzzy form of the mathematical model to classic form (crisp form) and then select an appropriate approach (heuristic, fuzzy programming, evolutionary algorithm, etc., or combination of the approaches) for finding the Pareto optimal solution.

Zimmermann (1978) started the application of fuzzy approach for solving fuzzy linear programming problems. Zimmermann (1976) also recommended a max–min approach, which was used for solving fuzzy mathematical problems with fuzzy parameters in objective and constraints. Sakawa & Yano,(1989) proposed an interactive fuzzy method for solving multi-objective nonlinear programming problems. Huang et al, 2006, developed an interactive procedure for solving multi-objective nonlinear problem for engineering design. Li & Lai, (2000) presented a fuzzy programming approach to transportation problem. A compromise programming model is formulated to provide a sound approach for decision maker's preference. Jimenez et al., (2007) proposed a ranking method for solving linear programming problems with fuzzy coefficients. They utilized the concept of feasibility degree to present optimal solution for several feasibility degrees to decision makers. Hu et al., 2007 proposed a novel approach for solving non-linear non-convex multi-objective optimization problem using evolutionary genetic algorithms to achieve higher satisfactory degree of decision making. Torabi & Hassini, (2008) introduced a multi-objective possibilitstic mixed integer programming model procurement, production and distribution planning. They introduced a method for transferring possibilistic model into crisp model and then proposed an interactive fuzzy approach for solving the problem. Pishvaee & Torabi (2010) proposed a bi-objective possibilistic mixed integer programming for solving closed loop supply chain network. An interactive fuzzy solution approach is developed by combining Jimenez (1996) ranking model, Parra et al. (2005) and Torabi & Hassini, (2008) compromising programming and aggregation function to obtain efficient solution.

The contributions in solution approaches can be divided in four categories: the utilized approaches for transferring fuzzy model to crisp model, solving the crisp model, and solutions approaches for each objective function, forming the overall fuzzy objective function of the problem and the compromising approach and finally the interactive process for involving the decision makers in solving process. For planning appropriate solution methodology for the EOL aircraft problem, we face several complexities. First of all, the nature of data and unknown parameters, the second one nonlinearity of multi-objective optimization model and finally the group of stakeholders and their role in decision making process. Hence, the proposed approach needs to have a mechanism to cover this source of complexities. In this part, we introduced a holistic approach for solving the proposed model in this study (Figure 94).

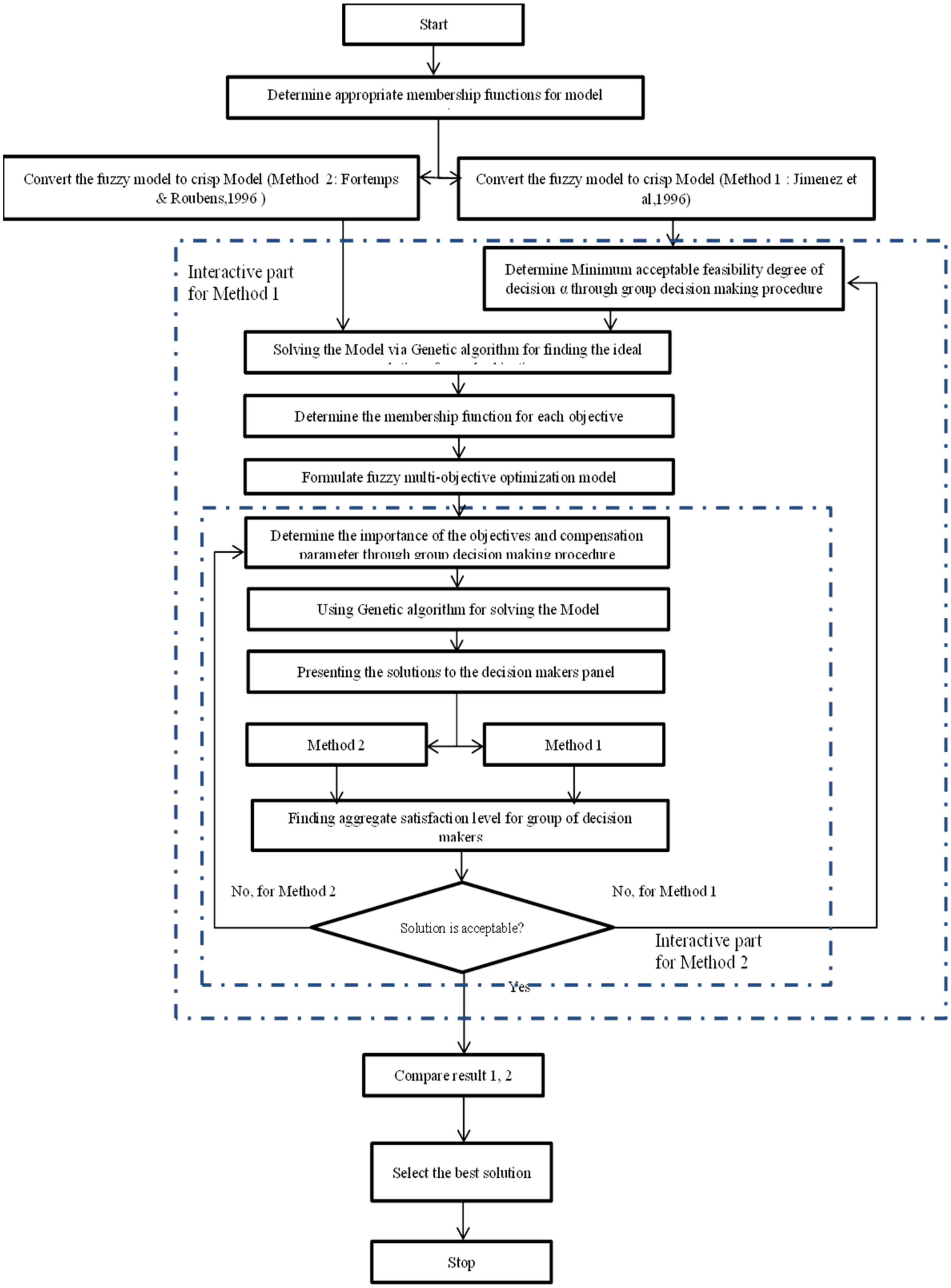


Figure 94 : The solution algorithm

Now, we describe the steps of the algorithm. There are different types of membership functions including linear (triangular form or trapezoidal) or nonlinear kind (exponential, hyperbolic, hyperbolic inverse or etc. (see Sakawa & Yano,

(1989) for details about these membership functions). The appropriate membership function can be selected based on the nature of parameters and decision maker's opinions. In this part for illustration purpose of the algorithm, we assume that, triangular membership function is selected (Eq. 5.3.36)

For transferring fuzzy model to crisp model, we utilized two approaches. The first method (Method 1) is Jimenez et al, 1996 method. This method uses expected interval and expected value for transferring the fuzzy form. Pishvaee & Torabi (2010) also mentioned several advantages of this approach including simplicity in computation and flexibility in using different membership functions. The expected interval and expected value for Fuzzy number A can be calculated as follows:

$EI(\widetilde{A}) = [E^1, E^2] = \left[\frac{1}{2}(a+b), \frac{1}{2}(b+c)\right]$ (5.3.38)

$EV(\widetilde{A}) = {(a+2b+c)}/{4}$ (5.3.39)

Multi-objective nonlinear programming model with fuzzy parameters based on (Sakawa & Yano, 1991, P.4) can be written as follows:

$\min f(x, \tilde{a}) = (f_1(x, \tilde{a}_1), f_2(x, \tilde{a}_2), \ldots, f_k(x, \tilde{a}_k))$ (5.3.40)

Subject to $x \in X = \{x \in E^n \vdots\ g_j(x, \tilde{b}_j) \le 0, j = 1, \ldots, m\}$

By applying Jimenez et al, 1996 approach the problem is transferred into crisp equivalent with α feasibility degree of decision x for triangular membership function as follows:

$\min f(x) = (f_1\left(x, \frac{a1+2b1+c1}{4}\right), f_2\left(x, \frac{a2+2b2+c2}{4}\right), \ldots, f_k\left(x, \frac{ak+2bk+ck}{4}\right))$ (5.3.41)

Subject to $x \in X = \left\{x \in E^n \vdots\ g_j\left(x, (1-\alpha)E_2^{bj} + \alpha E_2^{bj}\right) \le 0, j = 1, \ldots, m, \alpha \in [0,1]\right\}$

The second method (Method 2) is (Fortemps & Roubens, 1996) method in this method the fuzzy number can be written as follows:

$R(\widetilde{A}) = \frac{1}{2}\int_0^1 (\inf \widetilde{A}_\alpha + \sup \widetilde{A}_\alpha) d\alpha$ (5.3.42)

For the triangular fuzzy form, the above mentioned formula can be transferred into:

$R(\widetilde{A}) = \frac{1}{2}(a + c + \frac{1}{2}(c-a+2b))$ (5.3.43)

Hence, The Eq. can be written as follows:

$$\min f(x) = (f_1(x, R(\widetilde{a_1}))), f_2(x, R(\widetilde{a_2}))), \dots, f_k\left(x, R(\widetilde{a_k})\right)) \quad (5.3.44)$$

$$\text{Subject to } x \in X = \left\{x \in E^n : g_j\left(x, R\left(\widetilde{b_j}\right)\right) \le 0, j = 1, \dots, m, \alpha \in [0,1]\right\}$$

Before proceeding to solve each objective function with a suitable algorithm, in Method 1, we need to set the amount of α degree. In the problem of EOL aircraft treatment, we face key stakeholders which their decisions should be included in the solving procedure. It should be noted that considering the number of decision makers, group decision making models could be used to aggregate their opinions.

There are several approaches for finding optimal group consensus in fuzzy environment (see for example: Bardossy et al, 1993, Hsu and Chen, 1996, Lee, 2002) methods. Wang & Parkan, (2006) presented two approaches for evaluation of weights which could be assigned in group decision making models. Considering simplicity in computation and the strengths of this method in real life fuzzy group decision analysis and linear fuzzy numbers environment, we utilized the de-fuzzification-based least squares method (DLSM).

Assume that we have n stakeholders which their fuzzy opinions are triangular fuzzy number like $\widetilde{A_\imath} = (ai, bi, ci)$, defuzzified value can be determined by its centroid as follows:

$$z_i = \frac{\int_{ai}^{ci} x\mu_{\widetilde{A_\imath}}(x)dx}{\int_{ai}^{ci} \mu_{\widetilde{A_\imath}}(x)dx} = \frac{1}{3}(ai + bi + ci) \quad (5.3.45)$$

The relative weight of opinion $i(i = 1,2, \dots n)$ will be:

$$w^*{}_i = \frac{1/z_i}{\sum_{j=1}^{n}(1/z_j)} \quad (5.3.46)$$

The additive aggregation rule leads to the following result:

$$\widetilde{A} = \sum_{I=1}^{n} w^*{}_i \widetilde{A_\imath} \qquad (5.3.47)$$

In order to consider the salience of stakeholders and their power in decision making, we suggest the following relative weight.

$$\text{power\_weight}^*{}_i = \frac{1/S_{\text{actor}_i}}{\sum_{j=1}^{n}(1/S_{\text{actor}_j})} \quad (5.3.48)$$

$$w_i = w^*{}_i \times \text{power\_weight}^*{}_i \quad (5.3.49)$$

$$w^{*\text{total}}{}_i = \frac{1/w_i}{\sum_{j=1}^{n}(1/w_j)} \quad (5.3.50)$$

In this step, we need to solve each objective function (with all constrains) to find the ideal solutions and the boundary of the objective functions to form the membership function of these objectives. As the genetic algorithm (GA) provides sound solutions to complex optimization problems and considering the nonlinearity and complexity of the model (Liu B., 2009), the GA is used for solving each objective function. The general procedure of GA is as follows:

Step 1: Defining the appropriate chromosome for the problem

Step 2: Initialize population with a random numbers which satisfy all constrains

Step 3: Calculate the objective function

Step 4: Evaluate the fitness function

Step 5: Update the chromosomes by crossover and mutation

Step 6: Repeat step 3-5 as needed

Step 7: Find the optimal solution

With respect to the k objectives, we need to find k ideal solution. In this step we form the pay-off matrix $k \times k$ .For each objective function the lower bound and upper bound are defined and the following membership functions (for min and max objectives respectively) will be formed (Figure 95):

$$\mu_{f_k} = \begin{cases} 1 & \text{if } f_k \leq f_k^U \\ \dfrac{f_k^L - f_k}{f_k^L - f_k^U} & \text{if } f_k^U \leq f_k \leq f_k^L \\ 0 & \text{if } f_k \geq f_k^L \end{cases} \quad (5.3.51)$$

$$\mu_{f_k} = \begin{cases} 0 & \text{if } f_k \le f_k^L \\ \dfrac{f_k - f_k^L}{f_k^U - f_k^L} & \text{if } f_k^L \le f_k \le f_k^U \\ 1 & \text{if } f_k \ge f_k^U \end{cases} \quad (5.3.52)$$

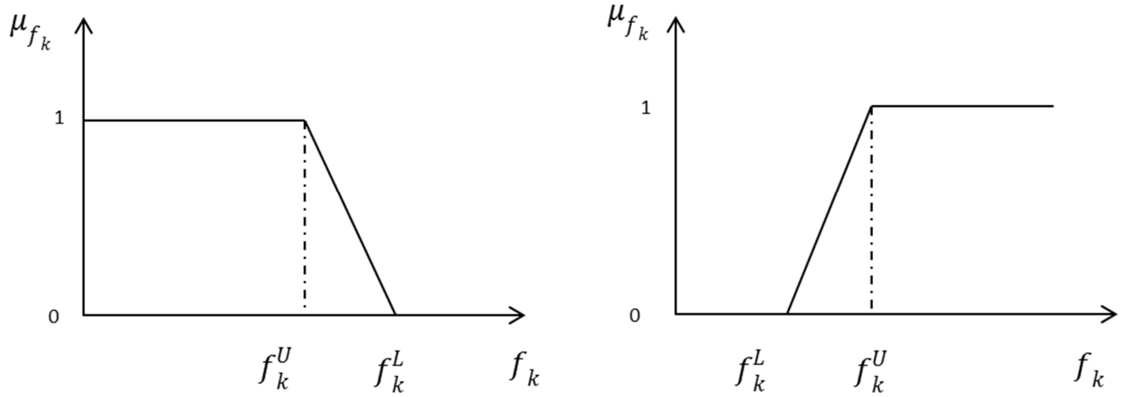


Figure 95 : min and max objectives membership functions

Now, we should covert the model into a single object model. There are several approaches for formulating the fuzzy approach to multiobjective optimization. Pishvaee & Torabi (2010) mentioned two approaches (Torabi & Hassini, 2008 and (Selim and Ozkarahan, 2008) for presenting the aggregation functions. With using the first one Torabi & Hassini, 2008), the Eq.43 can be re-written as follows:

$\max \lambda(x) = \rho^*\lambda_0 + (1-\rho^*)\{\omega_1^*\mu_{f_1}(x) + \omega_2^*\mu_{f_2}(x) + \cdots + \omega_k^*\mu_{f_k}(x)\}$ (5.3.53)

subject to $\lambda_0 \le \mu_{f_k}(x) \quad k = 1,2,\dots K,$

$x \in X = \left\{x \in E^n : g_j\left(x, (1-\alpha)E_2^{bj} + \alpha E_2^{bj}\right) \le 0, j = 1,\dots,m, \alpha \in [0,1]\right\}$

$\lambda, \lambda_0 \in [0,1]$

Where ω_k^* is the importance of the objective function k and ρ^* is the coefficient of compensation. As these numbers should be determined by decision makers so the aggregation procedure which explained in previous section will be used to find the consensus value. Now we need to solve this single nonlinear optimization model. GA can be utilized for finding the optimal solution. The final solution will be presented to group of decision makers and via fuzzy group aggregation procedure, the satisfaction level can be determined. If the satisfied result is not achieved the interactive procedure for method 1 and 2 will be repeated to find the efficient solution. At the end between the results of two methods, the best solution can be obtained.

5.3.7. Application perspective

This section reports application outlook of the proposed decision model and provides an administrative framework that allows EOL aircraft problem owner to understand the different aspects of the treatment process and organize the needed information in order to analyze the sustainability of the whole process. It also focuses upon the challenges in data collection and the significance of collaboration to forming and maintaining productive relationships among the players. The proposed approach and step by step guidance will aid decision makers to identify appropriate strategies for sub processes treatment considering sustainability indicators.

5.3.7.1. The nature of Data

According to (Pishvaee & Torabi, 2010), there are two sources of uncertainty in modeling the real problems: flexibility in constrains and goals and uncertainty in data. The uncertainty in data also referred to randomness of parameters or lack of knowledge about the parameters. The first one leads to stochastic programming and the second one leads to possibilistic programming. Jimenez et al., (2007) also mentioned that usually decision makers and experts do not know exactly the value of parameters. Even in the case of using the previous data, the statistical implications should be verified considering stability. In addition to this uncertainty, there are some parameters which are addressed by linguistic statement parameters. According to this reference, using interactive fuzzy approach is valuable to be applied in real-world problems with uncertain information or unknown or incomplete like environmental management or project investment.

In this study, we face both sources of uncertainty. There are some parameters without any knowledge about them (for example, the environmental impacts of different sub-process of EOL aircraft needs a life cycle analysis (LCA), this area of research is completely new and there are not enriched literature which address the environmental parameters precisely), social parameters or global business factors (like legislation) are also the parameters with complexity of availability or language statement format. Testing the model with real data is a complex task regarding the availability of necessary information. Siles, (2011) also in her study mentioned this difficulty and believed that the implementation costs, revenue form recovered parts and materials as well as the costs of chopping up operations and sorting scrap are in the categories of data that their availability are difficult. Thus, the pilot study of the proposed model requires the determination (exact or approximated) of all the data. Hence, fuzzy approach is an appropriate solution to deal with these uncertainties.

5.3.7.2. Guideline for application

Recycling complex products such as aircraft requires a high enhancement in engineering and management knowledge. A typical EOL aircraft project aims to study the best ways to disassemble, dismantle and recycle an EOL fleet with the objective of increasing the extracted value from recovered parts and recycled materials. Moreover, the ecological and social concerns should be taken into account. In these projects, an experimental platform will be selected for this purpose. Designing appropriate business models for recycling and logistics network are also the objectives of these projects. The best way for data collection and deployment of the decision making frameworks such as proposed by this paper, is case study approach.

Case study focuses upon the experimental platform under the study of the project with gathering the information from inter-organizational project team of engineers engaged in EOL aircraft recycling project in order to construct a guideline for managing the needed information for recovery network of treatment. Moreover, given the complex nature of the EOL aircraft recycling, a case study approach is extremely convenient. It aids partners and researchers involved in the project to study EOL phase of the aircraft with detail, providing a precise understanding of the different sub-processes of EOL aircraft treatment and the essential parameters that affect the sustainability of the whole process. Moreover, according to Yin, (2003), case studies also offer comprehensive and rich explanations of complex procedures and situations. The first stage of the data collection process may performed by review and discussion of the available information and reports regarding EOL aircraft problem. This process begins with explaining the information and the procedure which they may be used. The confidentiality of the information is stressed and highlighted that which type of data would be reflected in the final report and which type may be coded or changed due to privacy of information. Each participant (engineers or researchers in team) will be provided with an excel sheet including the tables for required information. They will be asked to fill up the tables based on their expertise or their observation through the execution of the relevant sub-task of the project. In the event of limitation of the information or difficulty of gathering such data, they need to specify them in the relevant place. Knowing the information related to the platform under the study of the project, the previous, current and next generation and the general characteristics are essential. This information can help to estimate the recycling and recoverability rate, the economics of valuable parts, prediction the number of retired aircrafts and other valuable insights for the problem. The main operators of the target platform, the number of actives planes, scrapped or stored ones and the average age of these planes are important information. The maintenance cost, production line situation, spare parts demand and commonality of parts are other information which should be collected in order illuminate the business model. The legislation is another important issue. If there is some phasing out regulation applicable for the planes, the motivation for retirements will be increased. The material composition of the plane which is contributed to the flow of material in the treatment process is also important data. Mapping the value chain and defining the boundary of the recycling chain and identifying the actors involved in the problem are the next steps. As described before, the process of recycling of the EOL aircrafts entails of several steps. For each step or sub-process the candidate companies for services should be determined. The related information with respect to the estimation of the capacity of site, required human resources and associated costs needs to be collected for each candidate. Recycling operation of the EOL aircraft has several environmental and social impacts which need to be considered. Sustainability analysis of the value chain provides this opportunity to assess and quantify these impacts. Life cycle assessment of the whole process provides information about the environmental impacts of the different sub-processes including Noise, Air emission, solid waste, waste of transportation and surface water and hazardous material impacts. In addition, social impacts can be evaluated via different criteria such as employment, risk to labour and local improvement. A panel of experts through a Delphi method can be used for estimation of the social impacts of different sub-processes. The related standards, regulations and practices for each sub-process should be determined. The Percentage of recoverable materials from platform's weight, in different sub-processes needs to be assessed. When the essential data are collected, the next step and decision model interface incorporating can be realized.

5.3.7.3. Incorporating with decision makers

The opinion of decision makers may have significant impact on the outcomes. Hence, appropriate interface for their involving is needed. Outsourcing decision cases, dismantling operation options, partner selections, capacity level, collaboration choices, distribution networks and performance trade-off cases could be utilized in order to provide an acceptable managerial insight to the recovery of EOL aircrafts. Decision support system could be designed in order to offer flexibility and simplicity of the model application. User friendly interface can decrease the complexity of the model and algorithm for pilot test. For visualization purpose, a simple example is illustrated in Figure 96. The EOL aircraft treatment network can be considered as a set of several contracts among the upstream, midstream and downstream of the value chain. It is supposed that there are three owner points, two candidates for parking sites, three part trading companies, three EOL enterprises, two dismantling facilities and recycling sites and three waste treatment sites. The decision maker panel window is shown in Figure 97. We assumed that decision regarding planning the optimum recovery network structure should be made by the collaboration of the owner (for example operator), EOL enterprise (the company who is in charge of planning and administration of the whole process), the authority representative (the local government or aviation authority representative) and the manufacturer of the fleet. After entering the weight of each decision maker, the importance of the objectives and coefficient compensation for each decision makers should be inserted into the model. Figure 98 shows the result window including the optimum results, the sustainability and performance measurement indicators as well as the best candidates for each sub processes. If the results are unfitting, we return to previous steps (e.g. reviewing the parameters) in order to attain satisfying results. A logical extension of this work would be then to evaluate the behavior of concrete cases.

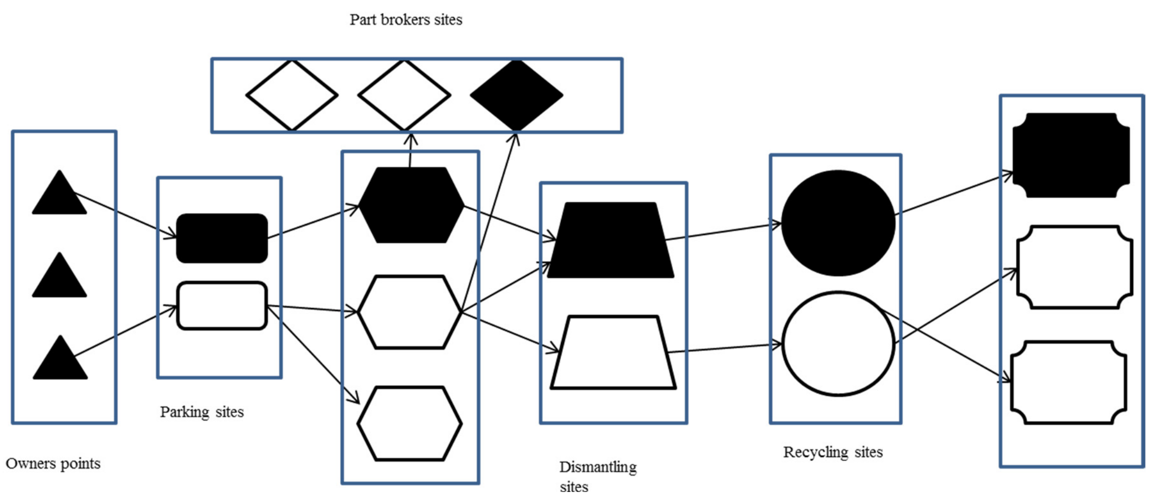


Figure 96 : Example of application of the model

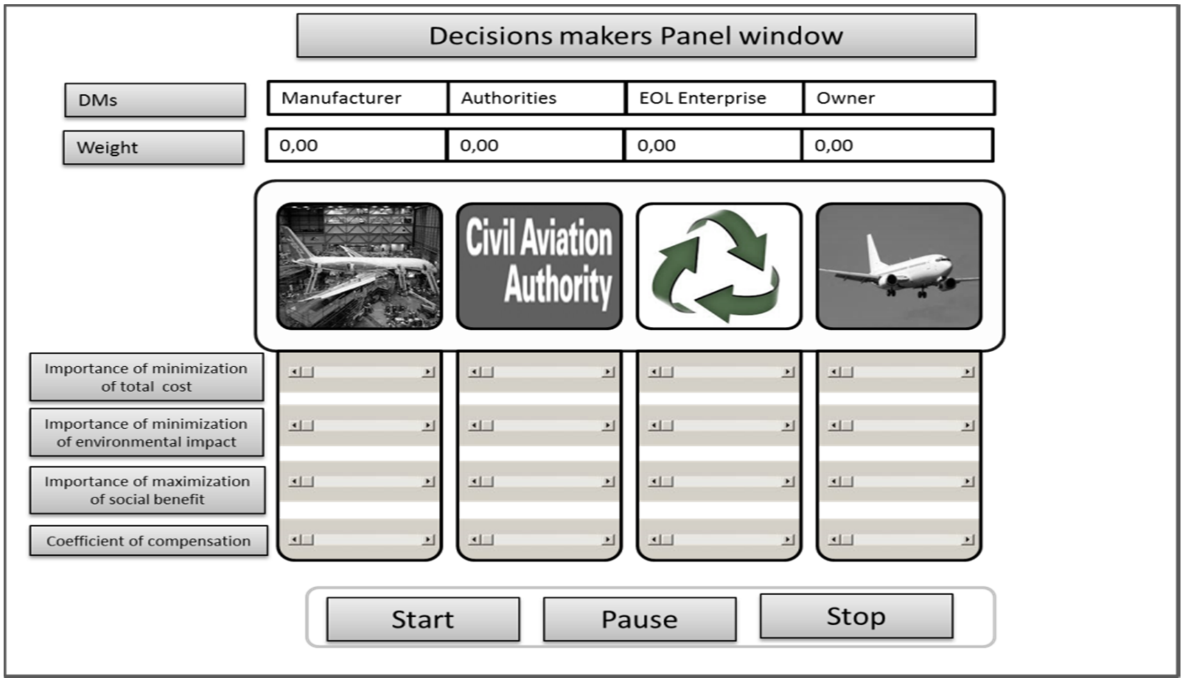


Figure 97 : Interface for trade off analysis (window 1)

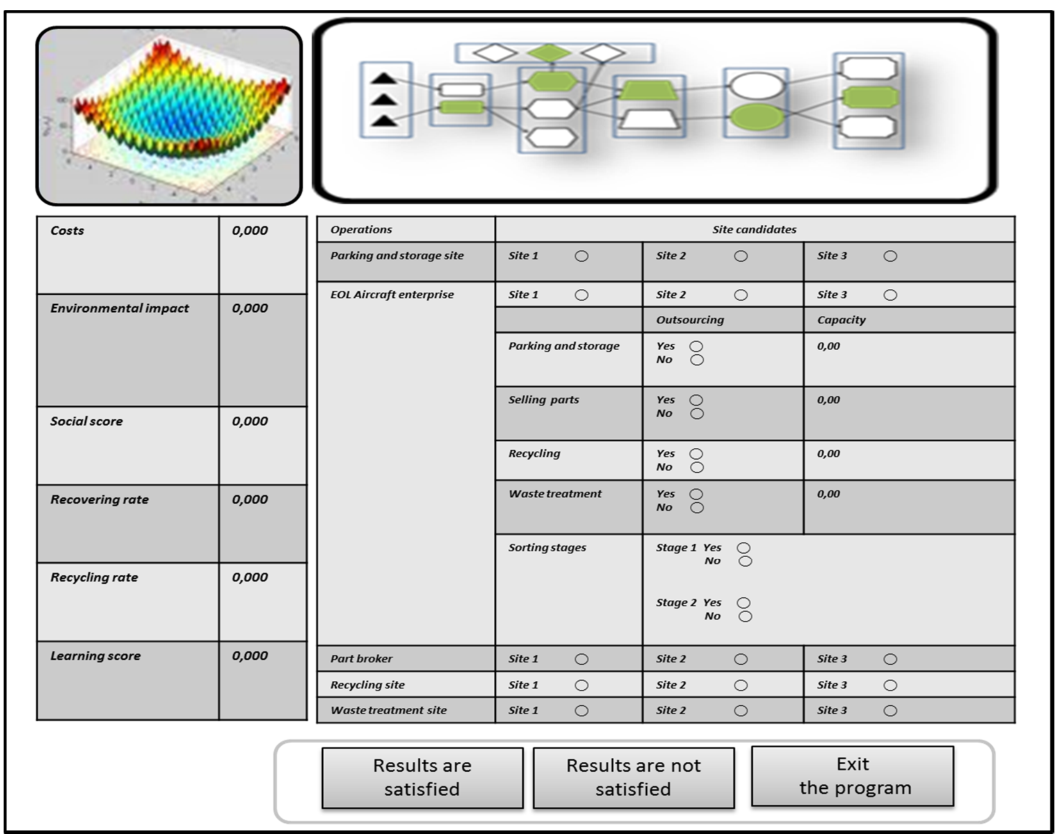


Figure 98 : Interface for trade off analysis (window 2)

5.2.8. Conclusion

Concerning the increasing number of aircrafts at the EOL in the future, there is needed to consider this problem as an industrial ecology problem in near future. Moreover, a potential business perspective for key players involved in the problem cannot be denied. There is not a systematic study that considers the logistic network of EOL aircraft treatment in the context of sustainable development, global business and lean management. In this paper, we developed an optimization model for analyzing EOL aircraft treatment network based on the holistic optimization framework introduced in part A of this paper. A multiobjective mathematical model is formulated to consider sustainability of the whole process considering the involved stakeholders in the problem. This study presented a solution approach based on interactive fuzzy decision making method for solving the multiobjective nonlinear program. The implications of this study are both theoretically and practically. From theoretical outlook, it demonstrates a starting point to develop an integrated framework for analysis the logistic network of EOL aircraft treatment. From practical point of view, it makes guideline for decision makers in order to handle the challenges related to EOL aircraft treatment. This information provides useful data for designing business model, especially at early stages of planning, as it defines which parts of dismantling process should be outsourced as well as the regions and areas of target business partners considering the material flows. This research, though, needs further investigation. The developed optimization model can be extended to take into account further aspects of EOL aircraft treatment. The detailed application of the model via a case study is also proposed as an essential venue for future research.

References

Airbus report, Global Market Forecast 2013-2032, retrieved from http://www.airbus.com/company/market/forecast/

Arenas Parra, M., Bilbao Terol, A., Pérez Gladish, B., & Rodríguez Uría, M. V. (2005). Solving a multiobjective possibilistic problem through compromise programming. European Journal of Operational Research, 164(3), 748-759.

Bardossy, A., Duckstein, L., & Bogardi, I. (1993). Combination of fuzzy numbers representing expert opinions. Fuzzy Sets and Systems, 57(2), 173-181.

Boon, J. E., Isaacs, J. A., & Gupta, S. M. (2000). Economic Impact of Aluminum□ Intensive Vehicles on the US Automotive Recycling Infrastructure. Journal of Industrial Ecology, 4(2), 117-134.

Boon, J. E., Isaacs, J. A., & Gupta, S. M. (2003). End□of□Life Infrastructure Economics for "Clean Vehicles" in the United States. Journal of Industrial Ecology, 7(1), 25-45.

Cruz-Rivera, R., & Ertel, J. (2009). Reverse logistics network design for the collection of end-of-life vehicles in Mexico. European Journal of Operational Research, 196(3), 930-939.

Dehghanian, F. (2010). Applying interactive multi objective decission making method in design of a sustainable recovery network to include different stakeholder's preferences. World Applied Sciences Journal, 8(5):596-607

Dehghanian, F., & Mansour, S. (2009). Designing sustainable recovery network of end-of-life products using genetic algorithm. Resources, Conservation and Recycling, 53(10), 559-570.

Fortemps, P., & Roubens, M. (1996). Ranking and defuzzification methods based on area compensation. Fuzzy sets and systems, 82(3), 319-330.

Hsu, H. M., & Chen, C. T. (1996). Aggregation of fuzzy opinions under group decision making. Fuzzy sets and systems, 79(3), 279-285.

Huang, H. Z., Gu, Y. K., & Du, X. (2006). An interactive fuzzy multi-objective optimization method for engineering design. Engineering Applications of Artificial Intelligence, 19(5), 451-460.

Jiménez, M. (1996). Ranking fuzzy numbers through the comparison of its expected intervals. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 4(04), 379-388.

Jiménez, M., Arenas, M., & Bilbao, A. (2007). Linear programming with fuzzy parameters: an interactive method resolution. European Journal of Operational Research, 177(3), 1599-1609.

Keivanpour, S., Ait-Kadi, D., & Mascle, C. (2013). Toward a Strategic Approach to End-of-Life Aircraft Recycling Projects, A Research Agenda in Transdisciplinary Context. Journal of Management & Sustainability, 3(3), p76

Keivanpour, S., Kadi, D. A., & Mascle, C. (2014). A Conceptual Framework for Value Chain Analysis of Aircraft Recycling in the Context of Sustainable Development Accepted in SAE 2014 Aerospace Manufacturing and Automated Fastening Conference & Exhibition

Latremouille-Viau, J., Baptiste, P., & Mascle, C. (2010). Airframe Dismantling Optimization for Aerospace Aluminum Valorization. In Frontiers of Assembly and Manufacturing (pp. 157-169). Springer Berlin Heidelberg.

Lee, H. S. (2002). Optimal consensus of fuzzy opinions under group decision making environment. Fuzzy sets and Systems, 132(3), 303-315.

Li, L., & Lai, K. K. (2000). A fuzzy approach to the multiobjective transportation problem. Computers & Operations Research, 27(1), 43-57.

Liu B., (2009) Theory and Practice of Uncertain Programming, 3rd ed, Springer-Verlag, Berlin, 2009.

Mansour, S., & Zarei, M. (2008). A multi-period reverse logistics optimisation model for end-of-life vehicles recovery based on EU Directive. International Journal of Computer Integrated Manufacturing, 21(7), 764-777.

Merkisz-Guranowska, A. (2010). Issues related to the optimization of location of vehicle recycling network entities. Archives of Transport, 22(3), 303-318.

Negoita, C. V., Zadeh, L. A., & Zimmermann, H. J. (1978). Fuzzy sets as a basis for a theory of possibility. Fuzzy sets and systems, 1, 3-28.

Pishvaee, M. S., & Torabi, S. A. (2010). A possibilistic programming approach for closed-loop supply chain network design under uncertainty. Fuzzy Sets and Systems, 161(20), 2668-2683.

Sainte-Beuve, D. (2012). Évaluation de différentes stratégies de démantèlement de la carcasse d'un avion Master dissertation, École Polytechnique de Montréal).

Sakawa, M., & Yano, H. (1989). An interactive fuzzy satisficing method for multiobjective nonlinear programming problems with fuzzy parameters. Fuzzy Sets and Systems, 30(3), 221-238.

Sakawa, M., & Yano, H. (1991). Feasibility and Pareto optimality for multiobjective nonlinear programming problems with fuzzy parameters. Fuzzy Sets and Systems, 43(1), 1-15.

Selim, H., & Ozkarahan, I. (2008). A supply chain distribution network design model: an interactive fuzzy goal programming-based solution approach. The International Journal of Advanced Manufacturing Technology, 36(3-4), 401-418.

Siles, C. (2011). Aide à la décision pour la gestion d'un parc d'avions en fin de vie (Master dissertation, École Polytechnique de Montréal).

Simic, V. (2013). End-Of-Life Vehicle Recycling-A Review Of The State-Of-The-Art. Tehnicki vjesnik/Technical Gazette, 20(2). 371-380.

Simic, V., & Dimitrijevic, B. (2012). Production planning for vehicle recycling factories in the EU legislative and global business environments. Resources, Conservation and Recycling, 60, 78-88.

Simic, V., & Dimitrijevic, B. (2013). End-of-life vehicle recycling in the republic of serbia: interval linear programming model for long-term planning under uncertainty.

Simic, V., & Dimitrijevic, B. (2013). Risk explicit interval linear programming model for long-term planning of vehicle recycling in the EU legislative context under uncertainty. Resources, Conservation and Recycling, 73, 197-210.

Torabi, S. A., & Hassini, E. (2008). An interactive possibilistic programming approach for multiple objective supply chain master planning. Fuzzy Sets and Systems, 159(2), 193-214.

Van Heerden, D. J , (2005) End-of-Life Aircraft :How to deal with an old aircraft withdrawn from service, Master dissertation(Unpublished)

Van Heerden, D. J., & Curran, R. (2011). Value Extraction from End-of-Life Aircraft. Encyclopedia of Aerospace Engineering. Wiley.

Wang, Y. M., & Parkan, C. (2006). Two new approaches for assessing the weights of fuzzy opinions in group decision analysis. Information sciences, 176(23), 3538-3555.

Yang, Y., Boom, R., Irion, B., van Heerden, D. J., Kuiper, P., & de Wit, H. (2012). Recycling of composite materials. Chemical Engineering and Processing: Process Intensification, 51, 53-68.

Yin, R. (2003). K.(2003). Case study research: Design and methods. Sage Publications, Inc, 5, 11.

Zadeh, L. A. (1999). Fuzzy sets as a basis for a theory of possibility. Fuzzy sets and systems, 100, 9-34.

Zimmermann, H. J. (1978). Fuzzy programming and linear programming with several objective functions. Fuzzy sets and systems, 1(1), 45-55.

Zimmermann, H.J., (1976). Description and optimization of fuzzy systems. International Journal of General Systems 2, 209–215

6. General Conclusion

This chapter summarizes the main research topics of this dissertation. It summarizes the essential learnings and resulting from the research. This chapter also provides opportunities for future research. The current aircraft supply chain is planned for the supply, production and distribution of new products. However, economic, environmental and social pressures push manufacturers to improve responsibility towards their activities and products. It leads to an increased motivation toward value creation or recovery from services and products through all their lifecycle, and therefore to the design and management of the value chain. The life span of most commercial aeroplanes is said to be around 30 years. Therefore, now there is a jump in number of plans at the end of life. The EOL phase of aircraft is a relatively complex phase in life cycle of this product. The retired Aircrafts need to be parked in a certain conditions. The valuable parts are disassembled and the rest of them are dismantled. Materials are separated and upgraded, waste is burned or deserted and toxic materials restrained or incinerated. All of these activities should be performed in an ecologically right manner; however, collectively produced added values for all stakeholders need to be considered.

EOL aircraft recycling is a fresh research theme and there are few works, which reflect some aspects of this problem. The absence of relevant directives in aviation industry, size of treated materials from End-of-Life aircrafts, the complexity and challenges in fleet recycling process, the multilayered relationship among players are only some characteristics that differentiate EOL aircraft problem from the rest of EOL recovery literature. Until now, in spite of few initiatives and practices regarding EOL aircraft recycling, there is not any integrated framework, or models for addressing different aspects of the end of life aircraft problem in the context of sustainable development. This thesis proposed a methodological framework for analysis EOL aircraft treatment value chain in the sustainable development context. Eleven publications have been produced, which present contributions of this thesis. The first paper addressed a research agenda that support various aspects of dynamics and transdisciplinarity of end of life aircraft recycling projects via a strategic conceptual framework.

Estimation of the number of ELAs, which generated each year, aids decision makers to set appropriate policies in order to manage the resulted waste and environmental impacts. The second paper reviewed the different approaches for prediction of the ELAs volume considering the challenges existed in the problem context. An integrated approach is proposed to provide a reliable methodology for estimation of retired fleet.

As an essential part of modeling and analysis of ELV recycling infrastructure is to capture the dynamic interactions among entities in this network of players, the third paper proposed a framework to integrate modeling and analysis of the complex interaction among players in automobile recycling infrastructure. Fourth paper presented a modeling approach based on fuzzy logic based system in order to analyze the economic sustainability of End of life vehicle (ELV) dismantlers under uncertainties. Paper five addressed the opportunities and challenges of applying green supply chain for aircraft manufacturers and analyses the different aspects of aircraft at the EOL in the context of green supply chain. The relationship between different operations of aircraft EOL problem and green supply chain elements also discussed. Paper six developed a decision tool to aid manufactures in early stage of design for their green strategy choices. This model provided manufacturers by an evaluation tool to select a portfolio of eco design practices to maximize the value perceived by all stakeholders in a dual life cycle approach including the business product life cycle as well as physical life cycle. Paper seven developed a model in order to analyze the strategic choice of manufacturers in response to EOL directives as the result of interaction of competitors in the market. Paper eight proposed an integrated conceptual framework for optimization of aircraft maintenance activities at the design stage considering reliability, economic, environmental and social performance. Paper nine developed an integrated framework for value chain analysis in the context of sustainable development. The value chain related to recycling aircraft at the end of life was chosen to generate an in-depth analysis of a value chain, considering environmental and socio-economic concerns. The value chain framework for recycling of fleet is identified. The key processes with environmental and social impacts are determined. The decision making process along the value chain and the policy framework including codes, regulations and standards are addressed. Finally papers 10 and 11 (A pair of papers) presented a novel holistic optimization framework and multiobjective mathematical model based on sustainable development, lean management and global business environment for EOL aircraft treatment. A multiobjective mathematical model is formulated to consider sustainability of the whole process considering the involved stakeholders. This paper also presented a solution approach based on interactive fuzzy decision making method for solving the multiobjective nonlinear program. Considering the novelty of this subject, this work provides a valuable framework for future research in this context. This study enriches the literature by identifying an integrated framework for vale chain analysis in the sustainable development context. Moreover, the illustrated guidelines in this study aid practitioner to realize the sustainable approach and stakeholder's involvement in decision making process.

Several perspectives can be developed in the future research which are suggested as follows:

- Applying the guidelines and decision tools in this thesis in a real case study as a pilot study
- Applying the developed framework for value chain analysis of EOL aircraft treatment in the other industrial context
- Extending the optimization model in order to taking into account further aspects of EOL aircraft treatment such as type of fleet, demand and price of recovered parts and materials, and uncertainty in business environments
- Developing a stochastic model in order to consider uncertainties related to the markets, to recovered products states and network operation context
- Designing a robust and sustainable value chain for EOL aircraft treatment