PRODUCT END-OF-LIFE PROBLEM IN THE CONTEXT OF REVERSE SUPPLY CHAIN ANALYSIS

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ABSTRACT
An increasing number of products are now arriving at the end-of-life (EOL). The total mass of mechatronics products and planes entering the EOL phase is large. Addressing the various aspects of the EOL problem is challenging for rural and urban managers. Due to factors such as the overall business of treating materials and toxic waste from aircraft EOL, the culture of secrecy and the complexity of aircraft, it is not easy to apply reverse supply chain and related treatment approaches to resolve this problem. However, practices and solutions applied for designing reverse logistics and the green supply chain for mechatronic industry can be adapted for the aerospace business context. The increasing importance of sustainable development means that the insertion of social and environmental concerns into the supply chain has become crucial for producers and waste, urban and rural managers. This paper addresses various issues in aircraft EOL and the effects of these problems on the original manufacturer's supply chain and dismantler's reverse chain. The objective of this paper is to provide a conceptual framework for analysis of the different aspects of the EOL problem in the context of reverse logistics and other related aspects. The relationship between different operations of the EOL problem and green supply chain elements is presented. Environmental and social impacts affect rural (aircraft storage and disposal) and urban areas (dismantling, spare parts storage, materials and toxic waste recycling). For the proposed conceptual framework, the challenges and opportunities with respect to applying these practices while considering the impact on supply chain are addressed in this study. In the context of green reverse supply chain, to evaluate the effects of applying effective planning and development for EOL practices it is essential to design a framework for performance measurement. Our results include proposals for better practices in aircraft EOL treatment. We can conclude that the conceptual framework is quite different for aircraft EOL treatment than for other products!
Keywords: aircraft EOL problem, reverse logistics, aerospace business context and performance measurement.

1 INTRODUCTION

Management of growing amounts of waste of all types is becoming an important challenge for the authorities of cities and countries, but also industrialists. Fifty years ago, one of three principal treatment strategies was applied at the end of life of a product: re-use, recycling or dumping. Use of other approaches was marginal. In the industrial sector, product end of life (EOL) was not a major concern; it was the problem of public administrators and retailers or recyclers. At the end of its originally intended service life, the value of an industrial product is compromised due to malfunctions, to breakage of some of its components or to obsolescence of components/functions. Some tougher new laws now impose constraints on industries, obliging them to modify their habits. It is therefore necessary to think of new strategies to optimize product life cycle and the treatment of products at their EOL. A particular case is the current aircraft industry, which is forced to adopt a product design process that includes EOL treatment (refurbishment, remanufacturing or upgrading, waste, reuse, recycling percentage, etc.). The Aircraft Fleet Recycling Association (AFRA) estimates that more than 12,000 aircrafts will be retired in the next two decades [1], between 6000 and 8000 commercial aircraft for Airbus and Boeing. The retired aircrafts need to be stored in dry, safe conditions. Their valuable parts are disassembled and the rest of the aircraft is dismantled. Materials are separated, waste is burned or dumped and toxic materials

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restrained or incinerated. All of these activities should be performed while considering environmental concerns and potential added value for members of related businesses. In this paper, the EOL aircraft recycling process is analyzed as a value chain and the different aspects of this problem are addressed in the context of sustainable development. The research field related to EOL aircraft recycling is still new and existing published literature is scarce. One research paper [2] provided an assessment of life cycle engineering in preliminary aircraft design. They propose an interdisciplinary approach in order to integrate sustainability issues. In this "Ladder of Lansink" approach, the first choice from an environmental point of view is re-using the aircraft parts as spare parts. Other choices include recycling or very often down-cycling or burning for energy recovery. Finally, in the event that none of these options are available, landfilling is the last resort. Another study [3] presents an evaluation of the difficulty of skeleton recycling due to use of mixed materials. The author believes that recycling the skeleton does not generate very high added value, though smart sorting can increase the extracted value from this operation. The work [4] proposes a mathematical model to optimize effectiveness of the aircraft dismantling process. This study differentiates between parts that must be sorted before shredding and those that can be shredded directly. Authors of study [5] developed a decision tool to maximize the profit of a dismantling process with respect to the sorting stages. They considered different scenarios for aircraft EOL treatment and introduced a mathematical model to help choose the best scenario depending on available time, costs and revenues. The research presented in this paper introduces a novel approach for analysis of the different aspects of the EOL aircraft problems in the context of sustainable development. Solutions are proposed for incorporating five EOL strategies into the management process. It includes the development and tests of elements for an integrated method of general management. The five EOL strategies are: reuse, refurbishment and upgrading, materials recycling via semi or non-destructive dismantling and recycling by shredding. The new methodology takes into account semi-destructive dismantling. It enables a reduction in time and costs for this operation while at the same time optimizing the quality of collected alloys, but is limited by the presence of two elements: the composition of primers and paints on parts and the presence of attachments (rivets for an aircraft).

The discovery of these elements and their influence on EOL options revealed the uncertain character of the data and the complexity of certain products and procedures in EOL treatment. We notice that for complex products with a long life cycle and period of development, interpretation of the results is complicated by uncertainties engendered by time, technological evolutions of manufacturing, maintenance, dismantling and rebirthing of products, changeable environmental, social and economic requirements. Further uncertainty is introduced by the varying composition of part primers and paints and presence of attachments.

2 BIBLIOGRAPHIC REVIEW

A survey of common practices is reported in the aerospace manufacturing industry regarding sustainability [6]. According to this study, the major practices can be divided into two categories: manufacturing practices and facility practices. The author divided facility practices into 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 benevolence. General practices include recycling initiatives, environmental awareness workshops or public activities aligned with environmental stewardship. The research concludes with potential gaps in these practices. Environmental efforts that are highlighted include material working and surface finishing due to the high energy consumed and chemical waste. 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. A significant lack in regulatory framework is noted, which makes the efforts promotional. A synthesis of literature related to sustainability in the aviation industry shows that there are several challenges with respect to aircraft recycling that should be addressed in future research. These include responsibility of manufacturers, effective feedback during the design stage, the different actors in recycling chain, the challenges of re-using and remanufacturing as well as reverse logistics.

Many industries have already moved in this direction, including automotive and consumer electronics. However, there are some major differences in treatment of EOL for aircraft. The volume of EOL aircraft is very small compared to that of electronics or 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 sub-assemblies with substantial market value, such as engines and landing gear [7]. The treatment of these aircraft must be economically attractive to produce value for all actors and advanced methods and processes are therefore required. The two largest airframe manufacturers, Airbus and Boeing, are at the head of major research projects in this field. Airbus initiated the PAMELA project with the objective of an 85 percent recycling and recovery rate by aircraft weight [8]. 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 [9]. 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 centres and universities to better understand end-of-life requirements and commercially practical recycling technologies for aircraft [10].

Value creation is a topic in the field of strategic management which has received a lot of attention on an individual and group level as well as an organization and society level [11]. According to [12], [13], value creation activities and processes must be understood based on the firm’s essential relationships with its stakeholders. The stakeholder view is based on 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 [13]. Based on this concept, the work [11] introduces a conceptual framework for a firm’s value creation. In this framework, stakeholder capabilities are defined as “the stakeholder effective opportunities to undertake actions and activities with the firm that they want to choose to engage in the value creation process”. We define sustainable value creation of the EOL aircraft recycling process based on this framework by adding rural and urban effects of rebirthing. The drivers of rebirthing include the reduction of rural and urban effects, regulation, stakeholders and competition in the aviation industry. The outcomes are comprised of tax growth, population health, innovation as the result of novel technologies and processes, cost effectiveness and reputation. Hence, the outcomes extracted from different sub-processes of rebirthing produce value for actors in the business loop. A value-added process can lead to actor satisfaction and this satisfaction is the source of actions and activities that re-generate value in the process.

Study [14] developed a sustainable-value framework that links the challenges of global sustainability to the creation of shareholder value by enterprise. In their framework there are vertical and horizontal axes. Based on this framework, we propose a novel approach to describe the chain of actors driving sustainable value in EOL aircraft rebirthing (Fig. 1). For each section the drivers are identified as well as the strategy and pay-off for actors involved in the problem. The vertical axis reveals the need of private and public managers to manage today’s sustainability and at the same time create tomorrow’s sustainable growth. The horizontal axis shows the need for private firm to grow and keep internal organizational skills

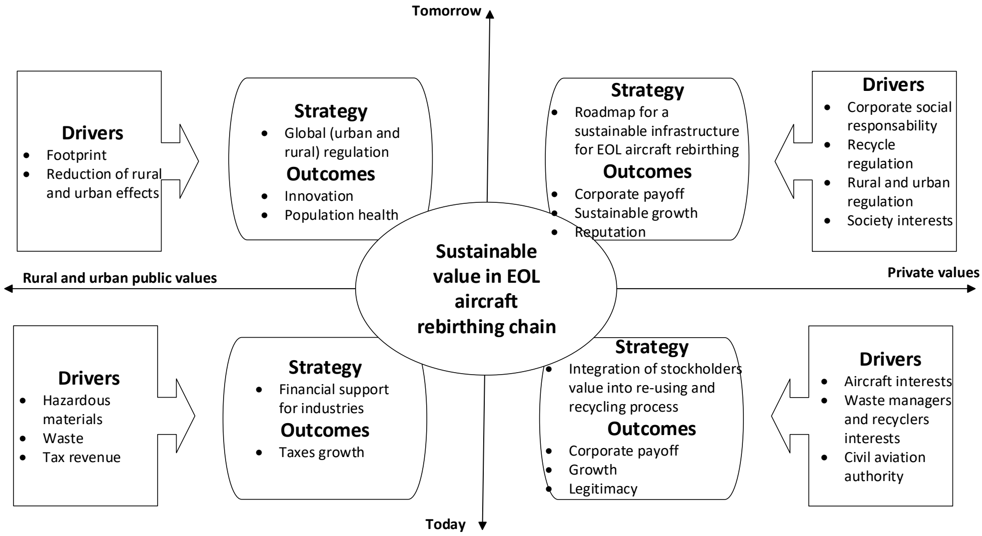

Figure 1: Driving sustainable value from EOL aircraft recycling chain.

and competencies while simultaneously pervading rural and urban organisations with new views and global regulation. 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.

3 SUSTAINABLE VALUE CHAIN

Fasse et al. [15] provide a systematic literature review of value chain methodologies considering globalization and ecological performance. Methods for evaluating harmful impacts of the value chain have become extremely important in recent years. These methods include Substance Flow Analysis as a subfield, Life Cycle Assessment and Energy Flow Analysis. This study emphasizes that the definition of system boundaries for integration of environmental thinking to the value chain is important because it can lower the cost of data collection and analysis. At the same time however, it may have adverse effects on the results due to truncation error. The work [16] presents a value chain analysis methodology for material flow in the UK iron and steel sector that considers economic and environmental dimensions. The authors 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". The study [17] introduces the application of Environmental Value Chain Analysis to product's take-back systems. The analysis studies the information, money and product flows between players. The players of concern include producers, government, consumers and recyclers. Even though the value chain analysis takes into account the environmental aspect, it is not a holistic approach for analysis of the value chain in a sustainable development context. The models, methods and approaches in supply chain analysis can be utilized however, for concept development.

3.1 Theoretical basis

Based on the analytic framework, proposed by Potts [18] and four categories of theories, 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 a value chain that takes sustainability consideration into account is discussed in this section.

In study [19], authors develop a 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. The integration of environmental thinking into the value chain has led to the development of some new concepts like the green-value chain and the 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 Savitz, The Triple Bottom Line approach evaluates the impact of an organization's activities on profitability, shareholder value and its social, human, and environmental assets [20]. Regarding the three dimensions, there are some specific criteria. For example, criteria for the economic aspect are sales, profit and monetary flow. Criteria for the environmental aspect include air quality, energy consumption and waste production. Finally for the social aspect criteria are labor issues and community impact. All these criteria can be considered during evaluation of the impact of an organization's activities. Based on [21] the performance measurement is defined as "the process of quantifying the efficiency and effectiveness of past actions". In addition, it can be explained as "the process of evaluating how well organisations are managed and the value they deliver for customers and other stakeholders" [22].

Performance measurement therefore 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 stakeholders. Suppliers are the main stakeholder in implementation of a green supply chain, but it is also necessary to identify other internal and external stakeholders and assess the impact of manufacturer's strategies on them [7], [23]. An alternative theory, resource dependence theory, proposes that in the supply chain, member firms should cooperate to find higher performance advantages in the long term instead of pursuing short-term benefits at the expense of others [24].

3.2 Conceptual framework

This theoretical basis was used to develop a conceptual framework for value chain analysis in the context of sustainable development (Fig. 2). The framework has four general steps, each with a few sub-steps. The first step starts with definition of the value chain, capabilities of actors (public and private) in the geographical region, various rural and urban impacts and identification of management problems including rural and urban trends, the effect of legislation and external factors that affect the value chain. The second step is identifying particular activities that have critical social and environmental impacts in both rural and urban areas. Political rules and interests are also identified. In this second step the exchange flows through the value chain based on triple bottom line theories need to be mapped. This enables sustainability analysis of the value chain. The third step of the framework includes identification of governance and inter-relationships and the identification of society interests. This step provides insights regarding the policy and decision-making process. Finally, the

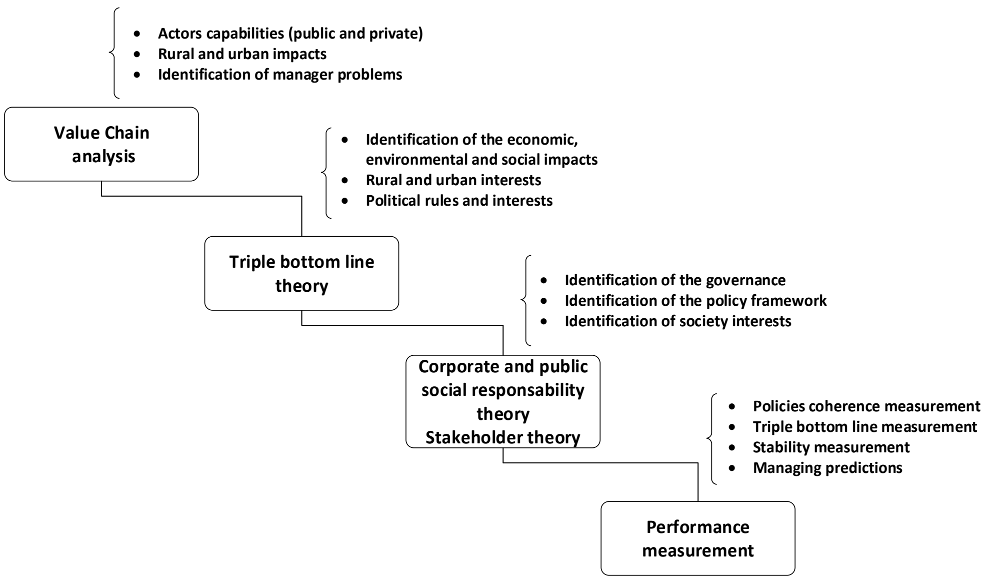

Figure 2: The conceptual framework for value chain analysis.

last step is performance measurement including the stability of the value chain, verifying whether environmental and social objectives are met, and evaluating the stability of the network of players and policy consistency over the chain.

4 APPLICATION IN AIRCRAFT REBIRTHING

The details and guideline for application of the framework are described for each of the four steps in the following sections.

4.1 Step 1: Value chain framework and problem context

This step provides more details about aircraft EOL and its value chain. We describe the information needed, the value chain of rebirthing, the length of the value chain and external factors that need to be considered. Before introducing the value chain of rebirthing, some information about the target of aircraft EOL is crucial. This information provides awareness about actor capabilities (public and private) and identification of management problems such as choice of dismantling operators, reuse options (as spare parts), recycling with or without disassembly, scrapping, burning and back-up information for understanding the economics of EOL aircraft. It also provides insights concerning essential rural and urban impacts including environmental and social challenges. Table 1 presents a list of useful information that needs to be gathered and analyzed.

Some practices and solutions applied for designing reverse logistics and green supply chain for the mechatronic industry can be adapted for the aerospace business context. Old-new concepts like modular disassembly can be significantly helpful to increase efficiency of the disassembly process; it is reported that over 30% of disassembly time is dedicated to the searching and positioning of tools [25]. The modular concept is proposed to enable use of a large number of tools during the disassembly phase for both manual and automated operations. Further details of the modular disassembly procedure can be found in research

Table 1: Useful information related to the EOL rebirthing value chain.

No	Information	The value of information
1	Aircraft type/range/spare parts	Rebirthing rate, spare parts value
2	Previous/current and next generation	Prediction of the EOL aircraft number
3	The amount can be recycled	Estimation of recyclability
4	Materials in structure	Material recovery channels, recycling and environmental challenges
5	Maintenance manual	Disassembling information
6	Maintenance costs	The motivation of the owners and operators for services
7	Usage history (age, cycle, hours)	The lesson learnt of operations
8	Operators	The decision of operators for dismantling, types of aircraft
9	Number of current/ parked/ scrapped	Prediction of the EOL aircraft number
10	Influence of legislation	Impact on the retirement of aircraft and phasing out

presented by Seliger et al. [26] and Duflou et al. [25]. Relevant techniques and available devices are specified in this work. Automation of all of these methods has been proposed as a viable solution. However, according to Opalić et al., manual disassembly has proved to be the most efficient method to date [27] for the following principal reasons: 1 – variety of products and collected parts to process; and 2 – the original product design usually does not favour ease of disassembly (design-related issues) [28].

Global trends and forecast also play an important role. For example, Current Market Outlook (CMO), Global Market Forecast (GMF) and Global Outlook for Air Transportation (GOAT) are some of main forecasts in aviation industry. The market for components and the number of aircraft to be scrapped, the effect of technological development on expected life time and the role of stakeholders are other factors that determine the problem context of the aircraft EOL business. According to [7] the role of component dealers, the demand for spare part components, and external factors, which include financial crisis and the demand for used aircraft are other elements that affect the economics of this value chain. The first step of a value chain analysis is mapping [29]. We need to define the boundary of the value chain of rebirthing, the actors involved in the problem and then 'map' or trace the flow of materials. Based on [29] a mapped value chain includes "the actors, their relationships, and economic activities at each stage with the related physical and monetary flows". Several major components can be disassembled before dismantling, recycling or disposal. Engines, landing gears, avionics, wind shields and electronic motors are some of the most valuable parts which may be reused. These parts need recertifying before they can enter the second-hand part market. Doors, wings, and interiors can be used for training purpose. Material recycling is another aspect of EOL solutions. Four major classes of materials are used, ranging from low-cost interior materials to high performance alloys and composites used in aircraft construction. Finally, the waste stream is send to a waste treatment facility for energy recovery or disposal. The value chain for EOL aircraft rebirthing is: Parking and Storage (h), disassembling (i), recertifying (j), dismantling (k), shredding (l), material sorting (n), recycling (r), and waste treatment (w). The EOL phase of aircraft may occur in various regions, thus the management of rebirthing needs to be considered in a global context. The different sub-processes for recycling can be done locally or outsourced to a third party. For this reason the problem needs to be assessed and analysed as a global value chain. Economics of scale are an important element in disassembly and recycling of discarded materials or environmentally friendly disposal of materials and should be taken into account. Furthermore, rural and urban authorities, environmental taxes and other global business factors need to be considered during the value chain analysis. For illustration purposes, the distribution location of some players of the operation for Montreal is shown in Fig. 3.

4.2 Step 2: sustainability analysis and value creation

Rebirthing of aircraft at their end of life has several environmental and social impacts that need to be considered. Life cycle and social assessment of the entire EOL process provides information about the environmental and social impact of the different sub-processes. Some recent research works focus on sustainability flow analysis in the logistics and supply chain frameworks. Study [30] proposes 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 include upstream and downstream effects along the supply and waste disposal chain. In work [31] a model is developed for measuring reverse logistics social responsibility performance based on the Triple Bottom Line approach. Two numerical examples are used to test the validity of the introduced approach. The economic value of the agent can be estimated by the amount of material and its value that are allocated to each successive agent. A novel concept is introduced in [32] to integrate the value, value creation and realization and value captures into the model presented in [31]. However, they show that the value capturing process needs to be assessed within the power relationship framework of buyers and sellers. This issue needs to be considered when formulating the economic value estimation and sustainability index of the value chain.

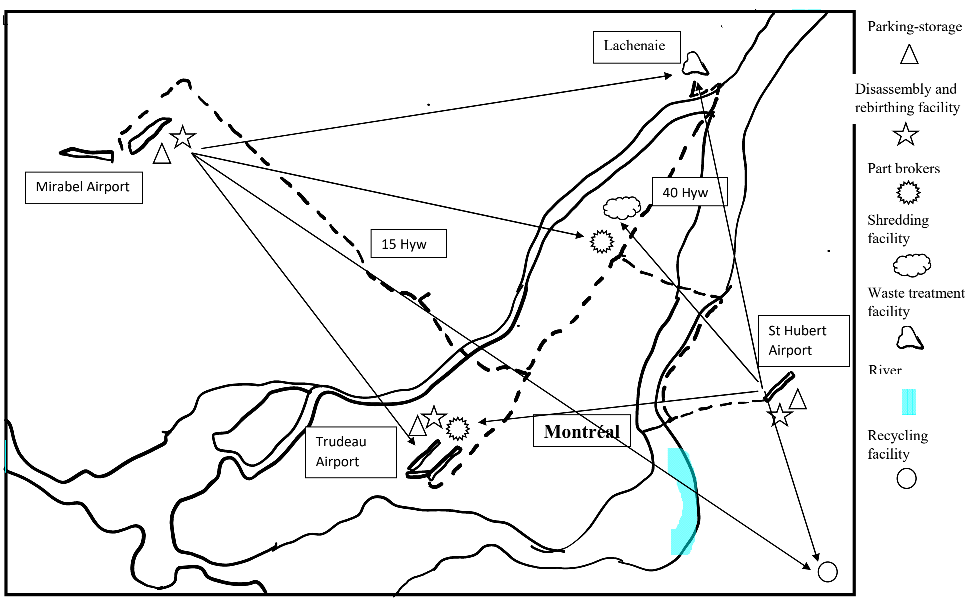

Figure 3: Distribution location of the players for the Montreal area.

4.3 Step 3: players, policy and governance

According to [5] various activities are involved during EOL treatment of aircraft, and this implies the involvement of different businesses and stakeholders. These include waste treatment companies, aircraft owners (airlines and financial institutions), part brokers (or maintenance specialists), smelters, recyclers, and legal institutions. It is important to add rural and urban managers to this list. When an aircraft is dismantled and recycled several regulations and laws must be respected. Further, some special rural and urban rules and regulation needs to be applied and some licences may be required. Based on the involvement of the different players, identifying the policy framework can aid in achieving internal consensus and also facilitate communication and reporting with external authorities. The policy framework can be studied in four levels including the policy level, standards, best practices and guideline and procedures. There are different approaches for studying inter-organizational relationships and governance mechanism. Transaction cost theory, social network theory and global value chain analysis are approaches for analysing the governance mechanism within a supply or value chain framework. Transaction cost theory determines factors for selection of exchange modes between actors. Social network analysis focuses on the all relationship in the network of players and global value chain analysis covers power relationship and the information exchange. A study of dyadic relationships between a buyer and the suppliers in a supply chain based on transaction cost theory analysed the role of the governance mechanism in the supply chain. The study concludes that two mechanisms; supplier assessment and supplier collaboration, have an impact on the environmental performance of the supply chain. The structure of the relationships among actors and their position in a network affect sustainability interaction, sustainability commitment, collaboration and success. Work [33] studied the governance of organizational networks and the impact of governance on network effectiveness. They introduce three models for network governance and, based on four aspects (trust, number of participants, goal consensus and the need for network level competencies), examined and discussed the effectiveness of each of these models. The first mode is participant-governed networks, in which network members governed themselves without any external entity. Governance in this form can be achieved by regular meeting among partners or by uncoordinated efforts. In this framework, involvement and commitment of all players is essential. This ensures that 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; network governance is done by a lead organization. In this mode, all major activities are coordinated by a single member who acts as a lead organization. In this model, network governance is highly centralized with asymmetrical power. The third model is a network administrative organization, in 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 the EOL aircraft recycling value chain, if we consider that the sustainability goal should be achieved through consensus, the shared governance model or network administrative model may be valuable. In addition, the number of participants depends on the involvement of different third-party players for the sub-processes of the operation. If we assume a few to moderate number of players in the chain, along with an expected high level of trust which is usually available in the 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 a typical governance model for the recycling value chain. Assessing the effectiveness of a collaboration format is a separate study. For example, forming a matrix of collaboration among players and analysing the power structure based on the social network theory is a sound method in this regard.

4.4 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 been defined for measuring performance within the aviation sector [7]. This section provides a review of some indicators that help evaluate the rebirthing value chain. The first main performance measurement is cost effectiveness of the whole process. The costs of rebirthing depend on various parameters. The overall arrangement of the process or outsourcing some sub-processes can affect the total costs. However, transportation costs (depending on the mode of transportation) need to be considered. Labour costs are significant during the dismantling and disassembling stages and depend on the skill and experience of the labour. In addition, the equipment, technology costs for sorting and material costs need to be considered. The rebirthing and recovery rate of the whole process is another index for performance measurement of the value chain. Study [7] discusses the recyclability and recoverability rate for EOL aircraft. The authors believe that these rates are linked to the success of the recycling process. In addition, these rates can be different when recycling the first aircraft of a particular model compared to the last aircraft of a model still flying. The potential for re-using the parts depends on the commonality of the parts and the similarity with models that are still being operated.

Environmental and social performance of the process is the next indicator for evaluation of performance of the operation. From the network perspective, the stability of the network is another index that can be used in the performance measurement framework. The stability and effectiveness of the 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. Considering the buyer–seller relationship upstream and downstream of a supply chain can help define the stability of the network. Therefore the governance structure of the network and the level of collaboration and selection of 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 in the upstream, midstream and downstream sections of the value chain, a stability measure of the social network and supply chain can be estimated. The last indicator for performance measurement is growth and learning across the value chain. As previously discussed, appropriate feedback during each sub-process of the operation can be valuable for aircraft manufacturers since this information can be considered during the design stage of future products. Moreover, growth of the chain in terms of acting as an infrastructure for recycling in the future (such as an ELV recycling infrastructure) can be another indicator for evaluation of the whole process.

5 CONCLUSION

This study introduces a methodology for analysing the value chain in the context of sustainable development. It proposes a conceptual framework to analyse the different aspects of the EOL problem in the context of reverse logistics and affected third parties. A value chain for EOL aircraft rebirthing was selected to show how the proposed approach can be applied. 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, which provides recommendations regarding effectiveness, efficiency and stability across the value chain. The implications of this study are both theoretical and practical. From a theoretical perspective, it provides a starting point to develop an integrated framework for analysis of the value chain in the context of sustainable development. From practical point of view, it provides a guideline for analysing the process of EOL aircraft recycling.

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