Transdisciplinary Engineering: Crossing Boundaries
M. Borsato et al. (Eds.)

doi:10.3233/978-1-61499-703-0-685

Aircraft Disposal and Recycle Cost Estimation

Xiaojia ZHAO[1] , Wim J.C. VERHAGEN and Richard CURRAN
Delft University of Technology, Kluyverweg 1, Delft, The Netherlands, 2629 HS

Abstract. The present study develops a method for the sake of evaluating Disposal and Recycle (D&R) cost in view of the increasing demand in aircraft retirement. Firstly, a process model is extracted. The subordinated cost elements are also identified. Next, the cost aggregations based on the D&R process steps are discussed. Moreover, it proposes an economic indicator to support the determination of the aircraft D&R strategies. The indicator is used to evaluate the economic performance and to facilitate the trade-off studies among different D&R scenarios. This analysis is demonstrated on two aircraft types with two scenarios. In addition, sensitivity analysis evaluating the impact of the salvage value, residual value, D&R cost, and the learning factor is performed. It is found that the engine D&R possesses more economic gains than that of the aircraft. The salvage value and residual value are the main factors which influence the D&R economic performance.

Keywords. Cost analysis, aircraft disposal and recycle process, disposal and recycle economic indicator

Introduction

Within the current commercial aircraft service, more than 8500 aircraft have been retired and it is expected that around 6600 aircraft would be retired in a decade [1][2]. This leads to the development of aircraft Disposal and Recycle (D&R), see Figure 1. The D&R process is related to the original design via the material choice and the component recyclability and recoverability [3]. It is associated with the aircraft status due to the operating and maintenance condition before parking. It is also linked with the engineering processes such as dismantling, sorting, and component management. Based on the aforementioned properties, it clearly indicates a transdisciplinary feature within the D&R process and the corresponding analysis [4].

Figure 1. Aircraft disposal and recycle (picture source: AELS website [5]).

[1] Corresponding Author, E-Mail: X.Zhao-1@tudelft.nl

Significant savings can be identified by comparing the labour, material, and energy consumptions for two processes: the D&R process of recycling an old component or produce recovered materials, and the manufacturing process of producing a new component or virgin materials. For example, it was found that the cost of manufacturing the virgin carbon fibre is around 15-30 US $/lb in 2011, while only 8-12 US $/lb is needed via recycling [6]. Moreover, recycling the aluminium material from scrap can save up to 95% energy, and producing recovered aluminium metals can reduce 39% energy consumption [7][8]. This is the main reason for the D&R process to stay competitive in the aviation market. However, due to the small industry size of the aircraft dismantling and recycling, few studies have been conducted on analysing the D&R process and its economic performance. The aircraft economics, the company economics, and the global economics often restrict the aircraft end-of-life solutions [3]. Along with the growing of the industry, it becomes necessary to conduct those analyses quantitatively. Literature shows that the aircraft disposal cost is around 10% of the purchase price or 1% of the total life cycle cost [9][10]. However, those rough estimates cannot improve the D&R process economic performance. Recently, research related to the disassembly sequence and its efficiency have been conducted by Dewhurst [11], Johansson [12], and Germani et al. [13] to support the product development, while a systematic approach is still needed.

The cost analysis is potentially an effective means of evaluating the commercial aircraft D&R process development, since it connects the product, process and cost throughout each process step and provides stakeholders with the economic estimates by aggregating the costs of the process steps. By considering the transdisciplinary analysis approach [14][15], end-of-life solutions of the commercial aircraft can be determined through a dynamic and adaptive system where diverse disciplines crossing boundaries can be handled.

1. Aircraft disposal and recycle process analysis

A generalised D&R process is shown in **Figure 2**. A process block represents a main process step or a group of sub-process steps. Some sub-process steps are listed in the brackets within each process block. The D&R process is determined based on the status of the aircraft and the customer requirements specifically for the recycle and reuse [3]. Some are stored in the aircraft boneyard, some are reconditioned and repainted for exhibitions, some are processed as recovered materials to be supplied to other products.

During the storing phase, the aircraft is transported, parked with or without performing maintenance activities. Whether the maintenance is necessary mainly depends on the aircraft current condition and its future usage. After deciding not to park the retired aircraft, it can either be reconditioned and recertified for resale and reused as a whole product, or be disposed of through a series of D&R process steps. When disposing an aircraft, it is firstly disassembled to get all the valuable components removed in order to be reused on the other aircraft or for alternative reuse. For a component to be reused on the other aircraft and engine, the component needs to be firstly recertified. If it is used alternatively such as for product exhibition, it often needs to be reconditioned. The airframe is dismantled by removing and scrapping hazardous materials, and it is cutted and shredded into pieces. Material sorting and separating are often performed manually right after the dismantling process. Depending on the material properties, the scrapped materials can be used for the secondary recycling, which is distinguished from the primary recycling for materials scrapped during the aircraft manufacturing processes. In general, the metal, glass, plastic, and composite parts are sorted out. Based on their sizes, different materials are supplied for respective recycling processes. Metal parts are firstly grouped by sizes. Then they are melted to be reformed to new parts. The composite parts such as Carbon Fibre Reinforced Plastic materials can be decomposed and the pure carbon fibres can be extracted. Those carbon fibres can then be reused as recovered materials for new components, which are often non-structural parts inside the aircraft or parts for automotive components and for electronic instruments. Two types of secondary recycling processes are divided in terms of the quality of the recovered materials. One is recycled without losing the material quality; the other is recycled containing paint/glue or recycled by the immature recycling techniques, lower quality materials are obtained accordingly, also called down-cycling. If the material cannot be recycled but can be burnt as wastes, the burning process will then converts the burning energy to heat or electricity, so-called energy recovery. In an ecological hierarchy, the last level of the end-of-life solution would be landfilling when the part/component material cannot be reused, recycled or used for energy recovery.

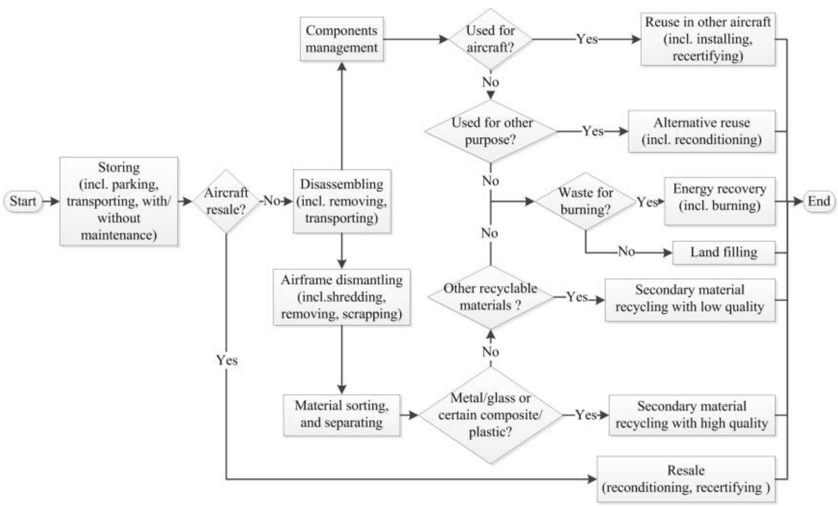

Figure 2. Aircraft disposal and recycle process model (adapted from [3] and [16]).

Taking a B737 D&R project as an example, the following process flow can be constructed: The aircraft is purchased and transported to the disposal site; then the systems such as the air conditioning, autoflight, and electrical power are removed, the engine and landing gear are also removed; some systems and engine parts are reconditioned, recertified, and reused for the other aircraft; the landing gear is scrapped; the airframe is shredded and the materials are sorted to be further recycled as recovered material. For a DC-9 project, the nose section, the engine cowl, and the landing gear are planned to be used for exhibition. The following process can be proposed: The aircraft is firstly purchased and transported to the disposal site; the engine cowl and the landing gear are removed, reconditioned, painted and transported to the exhibition site; then a D&R process similar to the previous one is conducted for the rest of the aircraft. Those two examples are constructed by referencing two D&R projects conducted by AELS [5], while the constructed process steps are conceptual for demonstration purpose and not necessarily the same as they were conducted.

2. Disposal and recycle cost estimation method and the economic indicator

The cost estimation method is developed based on the integration of the product, the D&R process, and the cost properties. According to the aircraft material usage and the customer requirements, the D&R process can be planned. The D&R process plan is generated based on the D&R process model and the rules embedded in the model. For example, if it is an engine part to be reused in other aircraft, the engine should be removed, repaired and recertified for reuse. Those process steps are set up sequentially for this specific case. When the engineering rules are sufficiently extracted, the process plan can be automatically generated. The total cost is formulated by summing up the costs of all process steps in a D&R process plan, see Eq.(1). The generalized cost function contains all possible process steps. When sub-process steps are subordinated to a main process step, the cost function can be further detailed. When only some of the process steps are conducted in a D&R process, only the costs of those steps count, others default as zero.

Next, the D&R cost can be obtained by aggregating each cost element defined in the Cost Breakdown Structure (CBS) for every D&R process step. During the cost aggregation, Cost Estimation Relationships (CER) and economic rates are utilised for calculations. The CBS of the D&R process step cost is shown in Figure 3. The total cost of a D&R project includes the labour, material, energy consumptions for each D&R process steps, the facility, tooling & equipment costs used to facilitate the D&R operations, the residual value related ownership cost, and the miscellaneous cost such as the overhead cost, shown in Eq. (2).

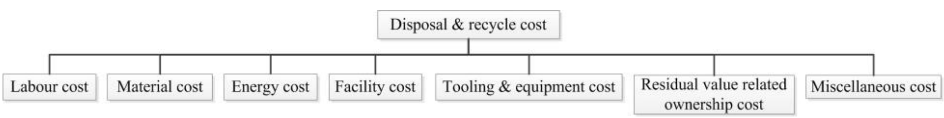

Figure 3. Disposal and recycle cost breakdown structures.

The cost estimation aggregates all cost elements for each D&R process step, see Eq. (3). The cost aggregations are shown explicitly through the labour, material, and energy costs. Since those three cost elements are directly linked to the process steps. Other cost elements, such as facility, tooling&equipment costs, are mostly one-time investments, which can either be estimated as a lump sum or be distributed over each D&R process steps to be aggregated later. The process step denoted as k refers to the D&R operations such as storing, maintenance, transportation, disassembly, dismantle, removing, sorting, reconditioning, scrapping, and recertification [17]. A process step contains a group of sub-process steps. For each step, all cost elements should be considered. For example, the storage of the aircraft contains the transportation of the aircraft, the maintenance activities before parking, and the aircraft parking process (see Figure 2). The aircraft transportation involves the costs of the crew (labour) and fuel (material); the maintenance cost contains the cost of maintenance mechanics and the cost of material used for repair; the parking cost includes the parking charge and maintenance labour/material consumptions during parking. Besides, there is also a residual value related cost element of the yearly investment for the disposal company to keep the aircraft for the moment based on its residual value. The aircraft residual value refers to the estimated aircraft price once it is retired. Eq.(4) shows the approximated residual-value-related cost, which is a portion of the aircraft residual value multiplies the number of years required for conducting the D&R process. In general, the residual value is around 10% of the aircraft price [18]. The yearly investment cost is approximately 5% of the aircraft residual value [16].

$$\begin{aligned} C_{D\&R} &= \sum_k C_{D\&R,k} = C_{D\&R,storing} + C_{D\&R,component\_managment} + C_{D\&R,disassembly} \\ &+ C_{D\&R,airframe\_dismantling} + C_{D\&R,material\_sorting\&seperating} + C_{D\&R,reuse} \\ &+ C_{D\&R,alternative\_reuse} + C_{D\&R,energy\_recovery} + C_{D\&R,land\_filling} \\ &+ C_{D\&R,recycling\_lq} + C_{D\&R,recycling\_hq} + C_{D\&R,resale} \end{aligned} \tag{1}$$

$$\begin{aligned} C_{D\&R,k} &= C_{D\&R,k,labour} + C_{D\&R,k,material} + C_{D\&R,k,engergy} + C_{D\&R,k,facility} \\ &+ C_{D\&R,k,tooling\&equipment} + C_{D\&R,k,residual-related} + C_{D\&R,k,miscellaneous} \end{aligned} \tag{2}$$

$$\begin{aligned} C_{D\&R} &= \sum_k C_{D\&R,k,labour} + \sum_k C_{D\&R,k,material} + \sum_k C_{D\&R,k,engergy} + C_{D\&R,facility} \\ &+ C_{D\&R,tooling\&equipment} + C_{D\&R,residual} + C_{D\&R,miscellaneous} \end{aligned} \tag{3}$$

$$C_{D\&R,residual} = r_{yearly\_residual} P_{residual} (1+I)^{FY-FY_0} n_{year} \tag{4}$$

where, $C_{D\&R}$ is the D&R cost. Different cost elements composing the D&R cost are also denoted. $C_{D\&R,residual\text{-}related}$ is the residual-value-related cost invested by the disposal company based on the yearly residual rate ($r_{yearly\_residual}$), aircraft residual value ($P_{residual}$) and years of keeping the aircraft (n_{year}). The yearly residual rate is assumed as 5% [16]. I is the inflation factor. When the cost is considered in the fiscal year FY other than the reference year FY_0, the influence of the inflation should be incorporated.

Furthermore, the salvage cost ($C_{salvage}$), extracted from the resale of the recycled components and materials, are considered as the value of the aircraft or aircraft component including the valorisation after the D&R process. Note that in this research, the salvage cost concept is interchangeable with the salvage value, which is defined as the actual or estimated resale price of an aircraft, engine or component based on the value of marketable parts that could be salvaged for re-use on other aircraft or engine or for other reusable purposes according to the International Society of Transport Aircraft Trading (ISTAT) [19]. Similar terms such as the part harvested value or the component market value are also utilised in the literature [2][16]. In order to provide a measure of the economic performance of the D&R process, a D&R economic indicator ($I_{D\&R}$) is proposed, see Eq.(5). It refers to the ratio between the valorisation and residual value of the aircraft. When $I_{D\&R} < 0$, the D&R process is economically inefficient cdxsince there is a lost during the D&R operations. When $0 < I_{D\&R} \le 1$, the anticipated valorisation recovers part of the aircraft residual value via the D&R process cost. Therefore, it indicates that the process cannot fully harvest the residual value of the aircraft. When $I_{D\&R} \ge 1$, the D&R process recovers the aircraft residual value or even larger. The process is profitable. In general, the bigger the D&R economic indicator is obtained, the better the D&R solution would be.

$$I_{D\&R} = \frac{C_{salvage} - C_{D\&R}}{P_{residual} (1+I)^{FY-FY_0}} \tag{5}$$

Moreover, when a disposal company repetitively performs similar D&R process steps for aircraft of the same type, the D&R process would gradually become mature. The labour cost based on the labour hour consumption will be reduced. This is analogous to the learning effect considered in the production process: when the number of aircraft or aircraft components to be produced is doubled, the labour cost of manufacturing one more product would get reduced [9]. It is often characterized as a logarithmic format. Similarly, by applying the learning effect to the D&R process, the D&R economic indicator including the learning effect for the Q^{th} aircraft can be expressed as Eq.(6). In order to capture and emphasise the influence of the learning effect, only the labour cost is considered to represent the D&R consumption, where Q_0 is the initial quantity of the aircraft which has gone through the same series of D&R operations, $r_{learning}$ stands for the learning factor.

$$I_{D\&R,learning} = \frac{C_{salvage} - \left(\frac{Q}{Q_0}\right)^{\frac{\log r_{learning}}{\log 2}} C_{D\&R,labour}}{P_{residual}(1+I)^{FY-FY_0}} \tag{6}$$

Since the cost estimation method and the proposed economic indicator are linked with the product properties and the disposal and recycle process steps, it can be implemented by combing the proposed functional capabilities with the current CAD/CAE software applications. In addition, the proposed method can also be integrated with available cost analysis tools.

3. Cost analysis and results

In this section, the analysis is conducted based on the data collected by the team SAI from three categories of responses from survey investigation [2]. The average cost of dismantling an airframe or engine classified by aircraft types can be seen from Table 1 and Table 2 [2]. The aircraft average residual value is assumed 10% of the aircraft average price, see Table 3. The D&R economic indicators can then be obtained (Table 4). Note that the term 'aircraft' shown in Table 1 to Table 4 refers only the airframe and systems without engines. For aircraft disposal and recycle, the R&D cost indicator of the regional jets is shown the highest value, while that of the wide body aircraft is low. This is because a regional jet often has a relatively low purchase cost but a high salvage value. For an engine dismantling process, the D&R activities for those three aircraft types are all profitable. This can be explained by the large salvage values of all recovered engines. A regional jet engine obtains the highest D&R cost factor, and it is followed by narrow body aircraft, then by wide body aircraft. This is similar to the trend shown by the D&R economic indicator for aircraft (without engines). Comparing the engine and the aircraft for all aircraft types, the economic performance of the engine D&R process is more profitable than that of the aircraft D&R.

Table 1. Average dismantle cost of an aircraft/engine (2014$) [2].

	Narrow body	Wide body	Regional jet
Aircraft	\$74,000	\$102,000	\$49,000
Engines	\$24,000	\$33,000	\$23,000

Table 2. Average value of parts harvested from an aircraft/engine (2014$) [2].

	Narrow body	Wide body	Regional jet
Aircraft	$1.5 million	$2.5 million	$2.0 million
Engines	$2.7 million	$3.7 million	$1.5 million

Table 3. Average aircraft price and residual value (2014$) (data resource for aircraft price [20][21][22]).

	Narrow body	Wide body	Regional jet
Aircraft price(total)	$87million	$ 263 million	$25 million
Engine price	2x$10million	2x$20million	2x$3million
Total residual value	$8.7million	$ 26.3 million	$2.5 million
Aircraft residual	$6.7million	$22.3million	$1.9million
Engine residual	2x$1million	2x$2million	2x$0.3million

Table 4. Average values of the disposal and recycle cost indicator.

	Narrow body	Wide body	Regional jet
Aircraft	0.21	0.11	1.03
Engines	2.68	1.83	4.92

In more detail, by taking the estimated costs of D&R process for a B737-300 project and a B747-400 project, a list of cost items are summarised in Table 5 and Table 6. The data resources come from the research conducted by van Heerden in 2005[16]. The B737-300 was built in 1986 with CFM56-3B-1 engines, and it was priced $133 million. The B747 was built in 1989 with CF6-80 engines, and the price was $59 million. Two D&R scenarios were considered: the disassembly and dismantle scenario and the resale scenario. The former refers to a disassembly and dismantle process immediately after the aircraft reaches the end of its life; the latter is to resale the aircraft after parking the retired aircraft for one year. The costs in Euro (€) are all converted to dollar ($) via the euro-dollar conversion rate in the fiscal year 2005, *i.e.*, €1=$1.18. Note that there are labour, material, and energy consumptions in transportation, maintenance, and project management processes, while they are not separated specifically for each process step due to limited data availability.

The D&R economic indicators for B737-300 and B747-400 evaluated for both scenarios are shown in Table 8. Obviously, the B737-300 disassembly and dismantle would fully recover the aircraft residual value with extra benefit, and the B747-400 would make a profit from the resale solution. Decisions on disassembly& dismantle or resale can be made through the comparison of the D&R economic indicators for different D&R scenarios.

Along with the increase of similar D&R operations for more aircraft, it is intended to capture the labour cost reduction using the learning effect incorporated D&R economic indicator. Assuming the evaluation is the initial D&R process for the first aircraft of both product types. The estimations for the *1st*, *30th*, and *300th* D&R operations using 80% learning factor are conducted for B737-300 and B747-400 respectively. Note that the learning effect is applied to the labour cost element within the disassembly and dismantle scenario; while for the resale scenario, the learning effect is incorporated in the maintenance cost element in this research. The results are illustrated in Table 8. It can be seen that the impact induced by the learning effect on the D&R process is reflected via the D&R economic indicator. However, since the labour cost consumed is much less than the salvage value gained, the influence of the learning effect on the D&R economic performance is little. The differences between the D&R processes for the 1st and 30th operations are slightly bigger than that between the 30th and 300th D&R practices.

Table 5. Disposal and recycle costs for B737-300 and B747-400 disposal and recycle projects (2005$) [16].

D&R process cost elements ($)		Disassembly and dismantle		Resale	
		B737-300	B747-400	B737-300	B747-400
Storing	Transport	-	-	177000	177000
	Parking (yearly)	-	-	3600	5400
	Maintenance (yearly)	-	-	159300	159300
	Investment (yearly)	-	-	135700	666700
Disassembly & dismantle	Labour	31860	123900	-	-
	Material	5900	11800	-	-
	Transport	3540	11800	-	-
	Scrap	2360	7080	-	-
	Equipment	17700	35400		
	Project management	7080	14160	-	-
	Overhead	2950	5900	-	-
Total D&R ($C_{D\&R}$)		71390	210040	475600	1.0e6

Table 6. Salvage values for B737-300 and B747-400 disposal and recycle projects (2005$) [16].

D&R process cost elements ($)	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
Salvage value	3.2e6	13.2e6	3.0e6	17.1e6
Aircraft residual value	2.7e6	13.3e6	2.7e6	13.3e6

Table 7. Disposal and recycle economic indicators for B737-300 and B747-400 disposal and recycle project.

D&R economic indicator	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
$I_{D\&R}$	1.16	0.98	0.94	1.21

Table 8. Disposal and recycle economic indicators for B737-300 and B747-400 disposal and recycle project.

D&R economic indicator	Disassembly and dismantle		Resale	
	B737-300	B747-400	B737-300	B747-400
$I_{D\&R,learning}$ (Q=1)	1.17	0.98	1.05	1.27
$I_{D\&R\_learning}$ $(Q=30)$	1.18	0.99	1.09	1.28
$I_{D\&R\_learning}$ $(Q=300)$	1.18	0.99	1.10	1.28

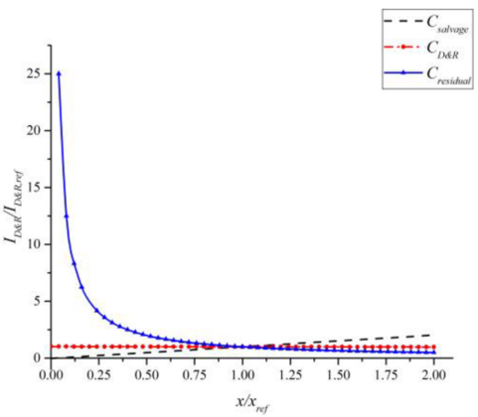

Figure 4. Sensitivity analysis for D&R cost indicator.

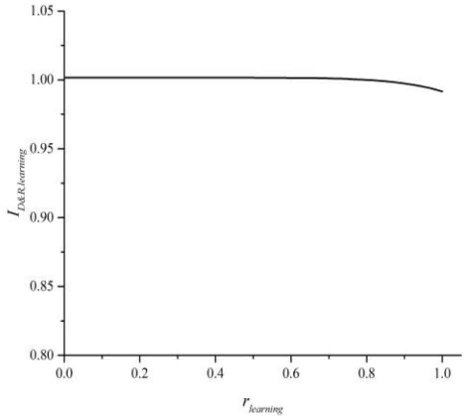

Figure 5. Influence of the learning factor to D&R cost indicator.

Additionally, in order to identify the impact of the driving factors for the D&R economic indicator, sensitivity analysis is exemplified for the B737-300 case. By applying $\pm 100\%$ margins to one of the parameters influencing the D&R economic indicator while fixing the other parameters, the corresponding changes reflected via the cost indicator are shown in Figure 4. The horizontal axis represents the change of the driving parameters, normalised by x/x_{ref}. It can be seen that the changes in the residual cost and the salvage cost are the main drivers of the variation of the D&R economic indicator. When the residual cost is reduced to be close to zero, the D&R economic indicator is raised drastically, which determines the economic performance of the D&R process. When the residual cost doubles, the D&R economic indicator gets halved. Increasing the salvage cost results in a steady increase of the D&R economic indicator. The increase of the D&R cost will slightly reduce the D&R economic indicator. Moreover, when varying the learning factor from 0 to 100%, the D&R economic indicator decreases within the range from 1.05 to 0.95, see **Figure 5**. It indicates that the slower the D&R process tends to mature, the lower the benefit would be obtained. Whilst the influence of the learning effect on the D&R economic performance is minor.

4. Conclusions

The present study proposed a D&R cost estimation method by means of integrating the product, process and cost properties. An economic indicator for the D&R process is also proposed, and it can be used to measure the overall performance of the D&R solution. Furthermore, such indicator can support the decision making, such as the disassembly and dismantle decision or the storing decision, within the aircraft D&R phase. It is found that the engine D&R possesses more economic gains than aircraft D&R. Additionally, the influence of the learning effect on the D&R economic indicator is studied. Results showed that the learning factor slightly impacts on the D&R economic indicator. This agrees with the sensitivity analysis, i.e., salvage value and residual value are the main factors which influence the D&R economic performance. The D&R cost has less influence on the economic performance of the D&R process.

Due to the fact that the salvage and residual values have significant influence in determining the D&R strategy, the methods that evaluate those two values need to be further investigated. Note that not all the cost elements are considered in this analysis, it might have reduced the impact of the D&R cost on the D&R economic indicator. It is therefore recommended to use cost parameters for each process step. Therefore, the cost drivers can be identified to support the development of the exact relationships between the parameters and the corresponding cost element. Other cost elements such as energy cost, facility cost, and tooling & equipment costs still need to be considered thoroughly in the future research.

References

[1] D. Forsberg, *Aircraft retirement and storage trends - economic life analysis reprised and expanded*, Avolon, 2015.

[2] N.N., *State of the aircraft dismantling & recycling business*, Team SAI Consulting, 2014.

[3] D. J. van Heerden and R. Curran, Value execution from end-of-life aircraft, in: R. Blocldey and W. Shyy (eds.) *Encyclopedia of Aerospace Engineering*, John Wiley & Sons, Ltd, 2010, pp. 3715–3726.

[4] S. Keivanpour, D. Ait-kadi, and C. Mascle, Toward a strategic approach to End-of-Life aircraft recycling projects - a research agenda in transdisciplinary context, *J. Manag. Sustain.*, Vol. 3, 2013, No. 3, pp. 76–94.

[5] AELS, "AELS projects," 2014. [Online]. Available: http://www.aels.nl/projects/completed-projects. [Accessed: 20-May-2014].

[6] P. E. George, W. L. Carberry, M. Connor, and B. Allen, Recycled carbon fiber performance in epoxy and polycarbonate matrices, in *Proceedings of the Composites Innovation Conference*, 2007.

[7] E. Asmatulu, M. Overcash, and J. Twomey, Recycling of Aircraft: state of the art in 2011, *J. Ind. Eng.*, vol. 2013, p. 108, 2013.

[8] H. F. Lund, *Recycling handbook*, 2nd edition. The McGraw-hill, 1992.

[9] D. P. Raymer, *Aircraft design: a conceptual approach*. 1989.

[10] J. Roskam, *Airplane design*. Ottawa, Kansas: Roskam Aviation and Engineering Corporation, 1985.

[11] P. Dewhurst, Product design for manufacture: Design for Disassembly, *Ind Eng*, no. 26, pp. 26–28, 1993.

[12] J. Jonasssin, Product innovation for sustainability: on product properties for efficient disassembly, *Int J Sust Eng*, no. 69–82, 2008.

[13] M. Germani, M. Mandolini, M. Marconi, and M. Rossi, An approach to analytically evaluate the product disassemblability during the design process, *Procedia CIRP*, Vol. 21, 2014, pp. 336–341.

[14] B. Nicolescu, Transdisciplinarity - past , present and future, in *CONGRESSO MUNDIAL DE*, 2006, no. Ii, pp. 1–24.

[15] T. J. Klein, Prospects for transdisciplinarity, *Futures*, vol. 36, no. 4, pp. 515–526, May 2004.

[16] D. J. van Heerden, *End-of-life aircraft: how to deal with old aircraft withdrawn from service*, Delft University of Technology, 2005.

[17] AELS, *Aircraft End of Life Solution (AELS) disassembly vs. dismantling*, 2014. [Online]. Available: http://www.aels.nl/disassembly-dismantling.Data Accessed: Jan., 2016. [Accessed: 20-May-2014].

[18] KPMG, *Components of aircraft acquisition cost, associated depreciation and impairment testing in the global airline industry*, 2007.

[19] I. Towle, *The aircraft at the end of life sector: a preliminary study*, 2007. [Online]. Available: users. ox. ac. uk/~ pgrant/Airplane% 20end% 20of% 20life. pdf. [Accessed: 20-Jun-2014].

[20] Airbus, *Airbus aircraft list prices*. [Online]. Available: http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/new-airbus-aircraft-list-prices-for-2016/. [Accessed: 10-Mar-2016].

[21] Boeing, *Boeing commercial aircraft list price*. [Online]. Available: http://www.boeing.com/company/about-bca/. [Accessed: 10-Mar-2016].

[22] Bombardier, *Bombardier commercial aircraft prices*. [Online]. Available: http://commercialaircraft.bombardier.com/en/media/list-prices---commercial-aircraft---bombardier.html. [Accessed: 11-Mar-2016].