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Six sigma with the blue economy fundamentals to assess the economic and environmental performance in the aircraft refueling process

Henrricco Nieves Pujol Tucci [a], Geraldo Cardoso de Oliveira Neto [a,*], Flávio Luiz Rodrigues [a], Biagio F. Giannetti [b], Cecília Maria Villa Boas de Almeida [b]

[a] *Industrial Engineering Post-Graduation Program, Universidade Nove de Julho (UNINOVE), Vergueiro Street, 235/249 – 12 Floor, 01504-001, Liberdade, Sao Paulo, Brazil*

[b] *Industrial Engineering Post-Graduation Program, Universidade Paulista, UNIP, R. Dr. Bacelar, 1.212, 4th Floor, 04026-002, Sao Paulo, Brazil*

A R T I C L E I N F O

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A B S T R A C T

The fundamentals of the blue economy promoting sustainable development by minimizing the consumption of fresh water, organic pollution and chemical contamination. On the other hand, the six sigma tool enables companies to improve the performance of their processes by reducing waste and statistical techniques. Not many works have been identified that related these two approaches, therefore, the objective of this work is to apply the six sigma tool with the blue economy fundamentals to assess the economic and environmental performance in the aircraft refueling process. The methods used were Return of Investment (ROI) and Mass Intensity Factor (MIF). A multiple case study was carried out involving two largest Brazilian airlines and the fuel distributor. The main results show the reduction of flight delays and, consequently, a decrease in the diesel consumption by trucks and energy generators, and water. The calculated economic gains were 52.9 million dollars annually and the environmental gains were the non-generation of 150 thousand tons annually. This work contributed to the theory for being the first to link SS in Aviation with measuring environmental benefits, even more so through the Blue Economy and to the practice for presenting to managers the possibility of obtaining economic and environmental benefits in the aircraft refueling process with no investment.

1. Introduction

The fundamentals of the blue economy underscore the objective of balancing the sustainable socio-economic development opportunities with the maintenance of the aquatic systems health [1]. According to Mulazzani and Malorgio [2] the Blue Economy is a strategy to promote sustainable development, recognizing that there is already an effort to use tools to reduce the contamination of aquatic systems [3]. Liu et al. [4] emphasize the relevance of protecting aquatic systems reminding that approximately 40% of the world's population lives 100 km from the coast, and industrial activities contaminate the water in rivers that drain into the Atlantic Ocean [5] and the North Sea [6]. Dalton et al. [7] adds that the main concern is the conservation of marine ecosystems, preventing the scarcity of drinking water and energy. Thus, it is important to establish a connection between the coastal environment and the enterprises, even those located in mainland, to reduce water consumption, as well as, minimize water pollution [8,9].

The blue economy is fast becoming one of the economic paradigms that most attract the attention of companies, however, there is still a lack of clarity in understanding its application in different businesses [9]. Even so, the consensus is that the blue economy may foster entrepreneurship to create sustainability, increasing engagement with entrepreneurs and boosting the United Nations Sustainable Development Goals [10,11]. Consequently, these companies would be closer to achieving sustainable development [12].

By adopting the blue economy concepts, companies are able to analyze the environmental impacts caused by industrial and residential wastewater [13], and identifying its effects, such as the environmental

Abbreviations: ROI, Return of Investment; MIF, Miss Intensity Factor; SS, Six Sigma; GPU, Generator Power Unit; MRO, Maintenance Repair and Overhaul; JET-A1, Most Used Civil Aircraft Fuel; IF, Intensity Factor; MIC, Mass Intensity per Compartment; MIT, Mass Intensity Total; SPC, Statistical Process Chart; APU, Auxiliary Power Unit; CGH, São Paulo Congonhas Airport; SDG, Sustainability Development Goals.

* Corresponding author.

E-mail addresses: henrricco@gmail.com (H.N.P. Tucci), geraldo.prod@gmail.com (G.C. de Oliveira Neto), rodriguesluizflavio@gmail.com (F.L. Rodrigues), biafgian@unip.br (B.F. Giannetti), cmvbag@unip.br (C.M.V.B. Almeida).

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degradation of water ecosystems: corals, fish and water pollution; being possible to develop a proactive strategy to establish environmental and social management in coral reefs, which may improve the health of the marine ecosystem and attract additional tourism [14,15]. Likewise, the marine energy and oil/gas sectors tend to adopt the fundamentals of the blue economy so that the economic, environmental and social impacts of their processes can be monitored and minimized [7,16,17]. Other sectors are also adhering to the blue economy to prevent damaging the water ecosystem such as the improvement of economic activities to minimize environmental pollution in fishing communities [8], requiring development business policies for the development of the Blue Growth sectors that involve aquaculture; offshore wind energy with fixed foundations; floating offshore wind energy; tidal and wave energy; marine biotechnology, mining under the sea; and tourism and recreation, based on depth and distance from the coast [18], also considering the involvement of fishing and aquaculture activities, mining on the seabed, marine chemical industry, shipping and transportation and manufacturing Blue Industry [19]. Weir and Kerr [20] calls for changes in rights to be accounted for in decision-making processes in the maritime sector, accompanied by better dissemination of information on rights at sea, governance and the future of the blue economy.

However, there is a lack of engagement in the voluntary adoption of the blue economy by companies [19], considering that most companies use water as a productive resource, and wastewater just goes into sewers, water treatment basins and water supply making it necessary to review corporate policies [18,20–22], encourage the updating of corporate governance [23] and investing in people's awareness [24] so that the benefits of the blue economy can be noticed by the community through long life to water ecosystems and eliminating residual water pollution [8,25].

In this context, investigating the linear and open characteristics of contemporary economic systems in relation to water pollution with chemicals and exaggerated consumption, impels researchers to study how industries can influence the sustainability of the system as a whole, including aquatic ecosystems, upon the blue economy lenses [26,27]. The treatment of effluents has been one of the options identified by companies to reduce production costs and increase the added value of their products while enabling the reuse of industrial effluents [11]. There is also a serious misalignment between the treatment of water pollution in relation to the efficiency of investments for the control and treatment of industrial solid waste and wastewater, requiring a blue economy strategy [28]. In addition, there is little information on the application of technologies in the effluent treatment process, especially in the sense of using the sludge resulting from this process, that is, the adoption of circular economy practices for the recovery of energy and materials [27]. This study fills this gap and direct companies towards the path of sustainable development based on the fundamentals of the blue economy by minimizing the consumption and pollution of the water used in the aircraft fueling process, as well as analyzing the operation of the effluent treatment station in order to guarantee the correct discharge to the aquatic ecosystem, which is even used for the treatment and supply of drinking water to the population.

Under this perspective, companies in the airline industry adopt tools to improve their operations, such as Six Sigma (SS), aiming to improve their operational and economic performance. However, the daily airport operations are responsible for many environmental impacts [29], some of which caused by aircraft refueling, a major cause of flight delays [30]. The process of aircraft refueling is usually carried out by tank trucks from a fuel distribution company and must be accompanied by an airline employee [31], however, time pressure and lack of attention increase the risk of failures in these maintenance activities [32]. One of the major problems during the refueling process is fuel spill that, regardless of the amount spilled, requires cleaning of the pit lane where the aircraft was parked [33]. In addition, each flight delay that exceeds 15 min, requires the aircraft to be connected to a generator power unit (GPU). In the present study, the adoption of SS in the aircraft supply operation generated detailed evaluation of these processes, making it possible to reveal, in addition to the operational improvement in flight delay, the environmental and economic gains obtained by minimizing the energy and water consumption, and reducing CO_2 emissions, denoting a practical and theoretical innovation under the perspective of the Blue Economy concepts.

Twenty-eight studies were identified in the scientific literature on the implementation of SS tools in the aviation sector operations covering qualitative and quantitative data on environmental, economic and operational aspects. SS was adopted in the operations of companies in the airline industry in: Maintenance, Repair and Overhaul (MRO) [34–36]; Flight Operation [37,38]; Aircraft Manufacturer [39,40]; Refueling [30,41]; Baggage Handling [42,43]; Warehouse Management [44]; Aerospace Manufacturing Supplier [45] and Product Development [46]. It is noteworthy that 22 studies mention only operational gains, 13 of which are quantitative studies and 9 bring qualitative evidence addressing: reduction of labor [31,38,44,47,48]; reduction in aircraft maintenance time [36,39,49]; reduction of operational failures [41,43,45,46,50–52]; reduction in flight delay [30,37,42]; improvements of project and risk management [53,54] and promotion of pedagogical strategies in training to reduce waste and rework [40,55]. It was also found that when research does not deal with operational gains, conclusions stick to economic gains in relation to increased sales [56] and economic gains with reduced maintenance [35,57], or simultaneously relate operational and economic gains in terms of reduction of operational failures at the MRO [58], increased availability of parts at the MRO reduced costs [34] and minimizing labor costs [59]. Thus, it was evidenced that there are few studies that addressed the economic aspects, even more if we consider only those studies that used a quantitative approach.

The systematic review of the literature supported the identification of works that applied the concepts of Six Sigma in Airlines in order to obtain operational and economic benefits. However, no work has been identified that related the application of Six Sigma in Airlines and carried out the quantification of environmental benefits, in addition, no work has been identified that related the application of Blue Economy concepts to Six Sigma or in Airlines.. Given this research gap, this work develops the following research question: How can the application of the six sigma tool with the fundamentals of the blue economy promote the improvement of operational, economic and environmental performance in the aircraft refueling process? Thus, the objective of this work is to apply the six sigma tool with the blue economy fundamentals to assess the operational, economic and environmental performance in the aircraft refueling process, as well as Fig. 1 shows.

Through the application of Six Sigma tools, the opportunity to reduce the amount of flight delays due to aircraft supply was identified. This reduction resulted in economic and environmental gains, consequently, theoretical contributions were obtained such as relating six sigma to the blue economy and quantifying the avoided environmental impacts, in addition to practical contributions such as improving operational performance and reducing emissions and pollutants.

2. Literature background on economic, environmental and operational gains of the SS tools adoption in aviation

One of the first companies to develop SS projects was General Electric (GE) in its aircraft engine overhaul unit aiming to reduce the time the engines stayed in the workshop [57], after all, the SS concepts help companies to reduce waste and eliminate failures [60,61] by means of statistical tools such as the control of process variability, thus, a process that reaches the six sigma level has a maximum of 3.4 products with defects in each batch of 1 million [60].

The systematic literature review investigated the application of SS tools in Aviation (appendix) and supported the observation that there are no studies that considered environmental aspects. In addition, few studies were identified that considered the economic aspects or that

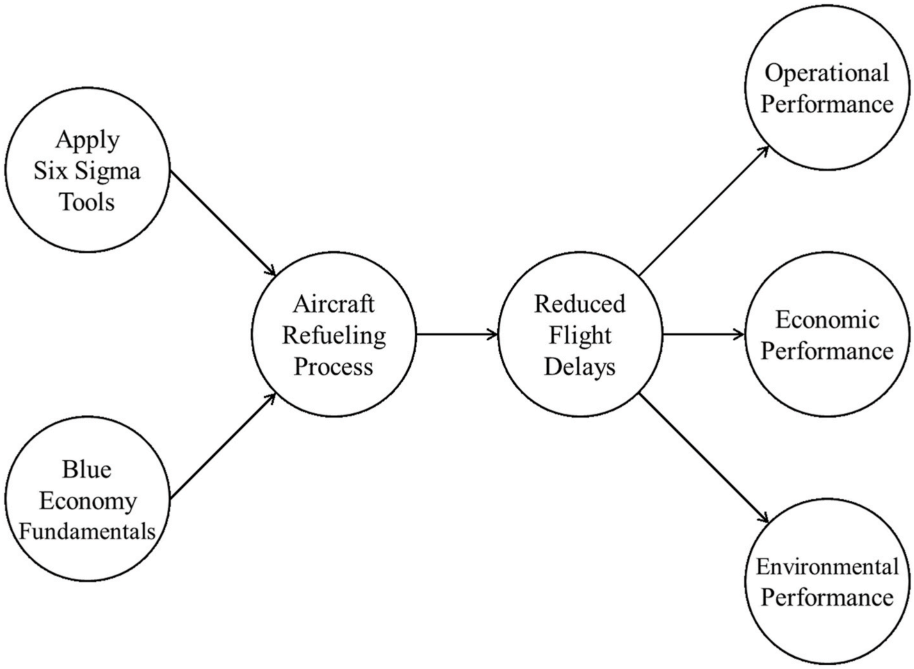

Fig. 1. Objective of the work.

used a quantitative approach. Maleyeff and Krayenvenger [58] studied the MRO operation in the United States and found operational gains in terms of reducing non-conformities that resulted in financial gain due to the elimination of rework. In India, Shanmuganathan et al. [34] found that SS optimized maintenance costs improving the operational performance. Ho et al. [53] concluded that the SS motivated Taiwanese employees to get involved in Green Belt projects bringing recognition and a sense of achievement in the implementation of operational improvement projects. Sumranwong [55] adopted the procedure in Thailand to improve the integration of industrial policies and pedagogical strategies to promote learning in the operating system. Among the four studies that used quantitative data, 3 studies evaluated the economic gain due to the implementation of SS tools in the MRO. In the US, Henderson and Evans [57], reported a gain of $ 1.2 billion, while Akbulut-Bailey et al. [56] declared that sales increased from $ 30 to $ 205 million a year. Pickrell et al. [48] recorded operating 50% of overall total cost reduction, reduction cycle time by 53%, reduction customer return backlog 82%, reduction support labor 32%, and increased capacity by 52%. In Europe, Thomas et al. [35] reduced £ 1,000,000 in the overall maintenance cost and Blockland et al. [49] reported a reduction of Turn Around Time to 13 days, generating operational gain. In India, Karunakaran [36] improved operational performance by eliminating waste and inefficient maintenance processes, reducing aircraft annual downtime by 78%.

In regard to Flight Operations, among the 5 articles involving SS describe quantitative and qualitative operational benefits. Higuera et al. [52] reported an improvement in operational performance of 34% for landing operations with the A380 aircraft in US. In a simulation carried out by Panagopoulos and Sikora [38], 99.954% of the total system safety performance improved under SS procedure, pointing 233 defects per million potential occurencies. In regard to qualitative evidences, Stolzer et al. [51] developed a study to eliminate defects by reducing fluctuation in processes to minimize tail strikes. Chaves et al. [54] reduced subjectivity in risk assessments and helped airlines to more effectively monitored flight events. Wei et al. [37] in China, resolved the programming delay, improved the ability to make use of data correctly and presented a more effective model of management.

The SS tools was also implemented in aircraft manufacturing companies. In Weber's quantitative study [50], tools were applied to reduce the weight of the combat aircrafts in a company in US, improving operational performance by reducing the number of parts by 37% and the number of fasteners by 46%. Chakravortya and Hales [39] achieved a reduction in setup time by 50% as an operational improvement in the process. In Brazil, Barbosa et al. [59] accomplished a reduction from 19 to 9.5 man-hours per aircraft, denoting operational gain and contributing to the annual financial savings by $ 57,000.00, and a training program on SS to generate operational gains was developed by Fonseca et al. [40].

Research targeting improvements in operational performance through SS in the aircraft supply process was carried out by through an ergonomic study in the control room of a fuel supply company [47]. Shackel and Klein [47] concluded that the change of layout and the setup of a state board would allow better control of the hour's extras, better work allocation and short rest breaks for crewmen. Babic [31] redistributed the refueller trucks, optimizing the scheduling and reducing manpower by 15%, and Ruamchat et al. [41] reduced incidents involving refueller trucks by 62.3% through a maintenance program. In Brazil, Tucci and Neto [30] identified the main responsible for the aircraft delays, and by implementing a new supply process, reduced delays by 57%. It is noteworthy that in all cases mentioned in the aircraft supply process there was an improvement in operational performance.

Concerning the Baggage Handling operation, Van Goethem et al. [42] reported an improvement in operating performance of 65% by reducing delays in flight connections due to baggage loading. Alsyouf et al. [43] reduced the number of bags waiting to be screened by 97.7%, improving baggage flow and operational performance.

Articles that implemented the SS tools in other operations in aviation were also identified. In the Product Development operation, Lee et al. [46] improved the performance of air vehicles operating under transonic flow regimes simulating the shape of the airfoil. In the operation of an Aerospace Manufacturing Supplier, Chaves et al. [54] developed a standard for through Continuous Improvement to allocate the resources supplied to the production system. Wong et al. [44] reduced recurring shipments by 40% and saved 71-man hours in the Warehouse Management operation.

However, no articles were identified in the literature that applied SS techniques in the aircraft refueling process and that quantitatively considered the operational, economic and environmental aspects. Regarding environmental aspects, this work was not limited to emission reductions, it analyzed the reduction in the use of energy and water, and even considered the proper treatment of effluents, and this was the link with the concepts of the blue economy.

It is important to mention the work of Sadiq et al. (2021) [62] that addressed the implementation of Lean Manufacturing techniques in conjunction with the fundamentals of the blue economy in a company in the automotive sector. The reduction in lead time and the reduction in CO_2 emissions were calculated, representing the economic and environmental benefits. However, this work did not show any relationship between the fundamentals of the blue economy and water care.

The fundamentals of the blue economy are a wide range of interconnected systems with the objective of exploring the preservation of water resources [63,64] and can be applied in coastal companies and with a direct relationship with the sea [7,15,16], for example, in the fishing industry [1,3,6,19]. On the other hand, there is a field of research in blue economics identified in the treatment of industrial waters [11,21], including works that address the reuse and recirculation of water from wastewater treatment station [27,64], that is, the application of the blue economy as a circular economy strategy.

In addition, there is a serious misalignment between the treatment of water pollution and the treatment of effluents and solid waste, while the first option is based on reactive actions, that is, they correct the problem after it has already happened, the second option is based in preventive actions, that is, seeking to contain the problem before crossing the company's borders [28]. Therefore, the fundamental of the blue economy was used to analyze the discharge of industrial effluent water from an airport.

3. Methodology

This work was developed at the airport with the largest number of domestic flights in Brazil. The two largest airlines located in the country were analyzed, named A and B, responsible of more than 97% of the total flights offered in the airport selected, along with the aircraft fuel distributor (JET-A1) and the airport management company. The aircraft supply process was investigated to identify the economic and environmental operational gains resulting from the reduction of flight delays due to the application of SS tools. Brazil is the sixth largest domestic air market in the world [65], and the airport selected is the second largest in the country in terms of number of passengers transported. The JET-A1 distribution company is the single fuel supplier at this airport, and the supply occurs through tank trucks. This aviation fuel distributor is present in more than 800 airports in more than 40 countries around the world. Companies A and B are internationally awarded airlines. The number of passengers carried by the two companies corresponds to the total transported by countries such as Turkey, Mexico or Australia.

For the multiple case study, quantitative data were collected through semi-structured interviews and included an adviser-memo to ensure that their content was standardized [66,67]. Field observations, document analysis and analysis of electronic systems were also carried out to identify flight delays related to the aircraft supply process [68].

3.1. Data collection procedures

The literature review of this work considered the search terms "aviation", "aircraft" and "six sigma" to identify in the literature the works that deepened the analysis of pollutant emissions in the atmosphere, reduced water use and rational use of energy. The research bases Science Direct, Emerald, Wiley Library, Sage, Compendex, Ebsco, IEEE and Taylor & Francis were used. The results of the content analysis made it possible to identify 28 relevant works that supported the systematic literature review. It is worth noting that content analysis is a crucial step to enable the literature review and refine the theoretical constructs that structure this work [66].

The data collection was developed in two stages. Firstly, data and information on the supply process of 100 aircraft were collected before the application of the SS tools, afterwards, 100 supply events were collected again to verify the application of the SS tools. This procedure was carried out for both companies. Thus, this work met the criteria of repeatability and reproducibility [69].

The companies were selected through an intentional sampling, and it was possible to adopt the 95% confidence interval for deviations measurement, such as adverse climatic conditions, human factors or interventions by the surveillance authorities [69].

The application of the SS technique was only possible because both companies invested in the formation of green belts and black belts in order to promote a culture of continuous improvement. The companies reduced their flight delays through the application of SS tools following the phases define, measure, analyze, improve and control, also known by the acronym DMAIC, a management tool for highly complex projects and that makes possible the use of statistical analyzes [60].

Therefore, the SS technique was chosen by both companies as they invested in the formation of green belts and black belts in order to achieve a culture of continuous improvement, through structured projects, with statistical support and that supported the calculations of the gains obtained [61].

In addition, the updating of national legislation has increased the collection of airlines in order to reduce flight delays and, consequently, improve the quality levels of services provided to passengers.

3.2. Data analysis procedures

The operational evaluation was based on the reduction of flight delays due to the application of SS from the alteration of the aircraft fueling process as proposed by Tucci and Neto [30] that is, the process only begins after information regarding the required quantity of fuel is physically passed through the flight dispatcher, and this information typically requires a certain time to reach the ground handlers, it is a bureaucracy problem (Fig. 2).

On the other hand, a new scenario was proposed focused on begin refueling with a minimum level and, if necessary, fill up the remainder with the final fuel figures when the information has received. With this change, the impacts of bureaucracies that caused flight delays were reduced.

As a result of the reduction in flight delays, it was observed (Fig. 3) that both airlines reduced the consumption of diesel oil from their generator power units (GPU) and tow tractor that load these units. Likewise, the fuel distribution company has also reduced diesel fuel consumption by its fuel tankers. A very important point observed was the reduction in the number of oil and fuel spills, thus reducing the extra fee payment to the airport administrator for cleaning the tarmac.

The economic evaluation was based on the reduction of the resources used and the accounting for avoided costs resulting from these reductions. This paper considered the concepts of Return on Investment (ROI) to identify economic gains. ROI calculation is possible by dividing net income by investment [70,71]. As there were no investments, all avoided costs were interpreted as economic gains. Therefore, it was not necessary to consider depreciation costs or interest and financing. It is worth noting that it is relevant to use a widely known concept in order to standardize applications and facilitate understanding, thus ROI is identified as a simple, clear and viable method [72].

In addition, it was observed (Fig. 2) that the reduction in the energy consumption generated by the GPU and the consumption of diesel oil by the tractors resulted in the reduction of environmental impacts by airlines A and B and the fuel distributor. Moreover, the reduction in the number of oil and fuel spillages events resulted in water savings and extrapolated the observation of the processes to the airport's wastewater treatment station. From this point on, this work identified the concepts of the blue economy as important to assess the correct destination of these effluents.

However, environmental assessment was a little more complex to develop than the aforementioned operational and economic

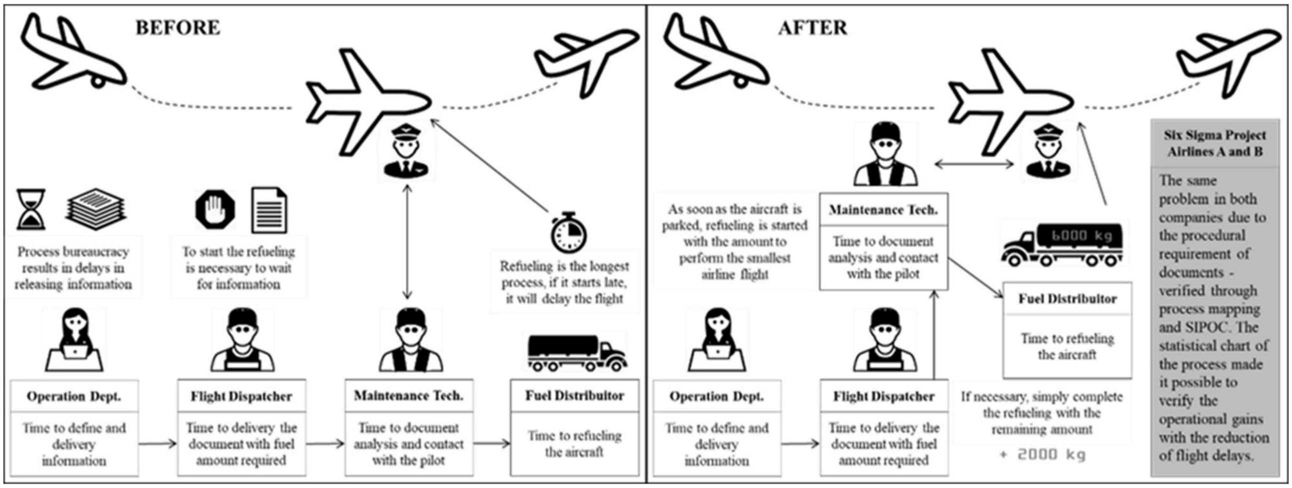

Fig. 2. Alteration of the aircraft refueling process by Six Sigma projects (adapted from Ref. [30]).

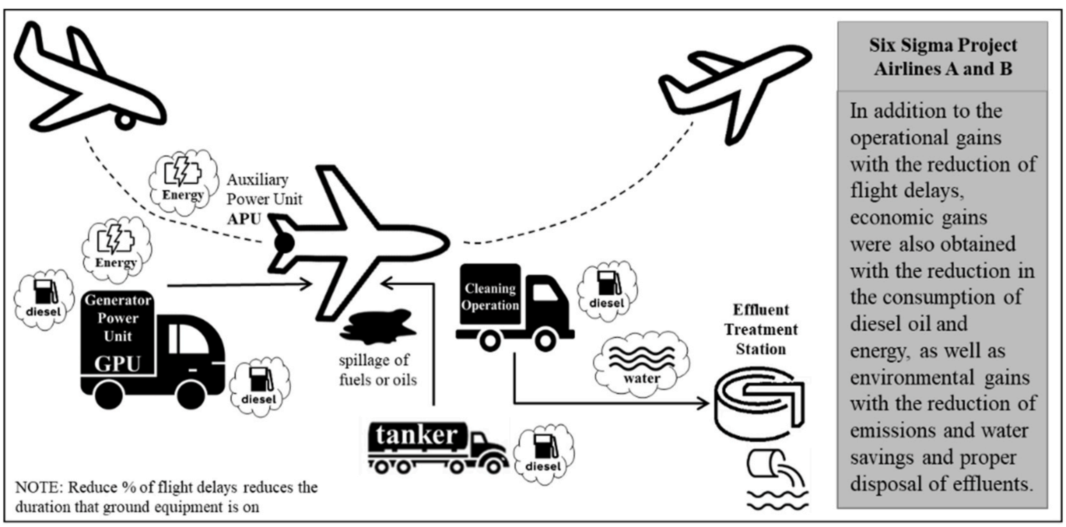

Fig. 3. Operational, economic and environmental aspects of Six Sigma projects.

assessments. The direct relationship between the increase in pollutant emissions and the worsening of environmental aspects is not new [73], but the quantification and calculation of environmental impacts due to the consumption of different materials, as well as their effects in different environments is a challenge without a standardized response [74,75].

The environmental assessment of this work followed the model inspired by the work of Oliveira Neto et al. [76]. The first step was to quantify all the residues and emissions produced to create a mass balance table. In this work, the information collected was related to the consumption of diesel oil by the vehicles and the generator, in addition to information on the amount of water used to wash the tarmac due to oil and fuel spills. Then, the quantities of diesel and water were converted into mass (M).

The second step was to consult the work of the Wuppertal Institute [77] to identify the Intensity Factor (IF) of each material, in this case, diesel, water and oil (Table 1). IF is the quantification of environmental impacts, an important point is that environmental impacts are considered in four different compartments: abiotic, biotic, water and air.

With this information, it was possible to use Eq. (2) to calculate the Mass Intensity Factor (MIF) of each material and in each compartment.

$$MIF = M^{*}IF \tag{2}$$

The third step was the calculation, using Eq. (3), of the Mass Intensity per Compartment (MIC) consolidating the data of the different materials for each compartment: abiotic (w), biotic (x), water (y) and air (z).

$$MIC = IF(residue\ \ A\ \ compartment\ \ w) + IF(residue\ \ B\ \ compartment\ \ w) + IF(residue\ \ C\ \ compartment\ \ w) + \dots \tag{3}$$

The fourth and final step was the calculation of the Mass Intensity Total (MIT), using Eq. (4), consolidating all materials and all compartments.

Table 1
Intensity factors (adapted from Ref. [77]).

Intensity Factor	Abiotic	Biotic	Water	Air
Water (cleaning)	0.01	–	1.30	–
Diesel (emission)	–	–	–	3.20
Oil (spilled)	3.19	–	18.72	1.89

$$MIT = MICw + MICv + MICz + MICn \tag{4}$$

Therefore, the value presented by MIT is equivalent to the avoided environmental impact of diesel and water materials, in the abiotic, biotic, water and air compartments. That is, the value of MIT is equivalent to the environmental gain.

In order to exemplify the MIF methodology, Fig. 4 below shows the example of the annual water savings that an industrial process achieves by using the resource rationally.

The evolution of these four stages made it possible to calculate that using water in a rational way enabled the company to avoid the environmental impacts of 9563 kg per year in abiotic, biotic, air and water environments. In other words, environmental impacts in the abiotic and water environments were avoided, on the other hand, water does not cause impacts in the other environments and therefore were not calculated.

The study by the Wuppertal Institute [77] calculated in laboratories the intensity factors of different materials, fuels, transport services and food, for each of these items the environmental impacts in the abiotic, biotic, water, air and earth compartments were considered. In the case of the latter, erosion and mechanical earth movement were considered.

Therefore, this work applied the methods presented ROI and MIF in the SS projects, together, the fundamentals of the blue economy was applied. Given the congruence of these techniques, this study sought to achieve the proposed objective of analyzing the improvements in economic and environmental performance in the aircraft refueling process.

4. Results

The application of SS tools made it possible to identify that changing the aircraft fueling process would allow companies A and B to reduce flight delays (Fig. 1). The flow of information to supply aircraft was frequently interrupted by bureaucracies, as presented by Tucci and Neto [30], a change was made in the information flow of the process, the fueling was started with a minimum amount of fuel, enough to attend the shortest airline's flight, so, when the information with the final value of fuel required was arrived, the fueling process was started again to fill the remaining amount of fuel and minimize the impacts of bureaucracy problems in the process. These improves the aircraft fueling process by SS tools and reduces flight delays, which accounted for 57% for company A and 43% for company B. The results presented in the statistical process charts (Fig. 5) boosted the reassessment of the aircraft supply process to analyze the economic and environmental aspects.

During refueling, energy supply to the aircraft is maintained for the operation of air conditioning and lighting, and the flight remains connected to a GPU, allowing the aircraft's Auxiliary Power Unit (APU) to be turned off, since the APU consumes up to 20 times more fuel than the GPU.

In case flight is not released at the scheduled time, employees involved in servicing are pressured to complete pending multiple tasks simultaneously as quickly as possible increasing the risk of failures. One of the most common failures is the spillage of fuels or oils in the tarmac that, when occurs, activates the airport manager to perform the appropriate cleaning to mitigate the risks of operational and environmental accidents. The airline has to pay an extra fee for this cleaning operation and for using the tarmac beyond the planned period.

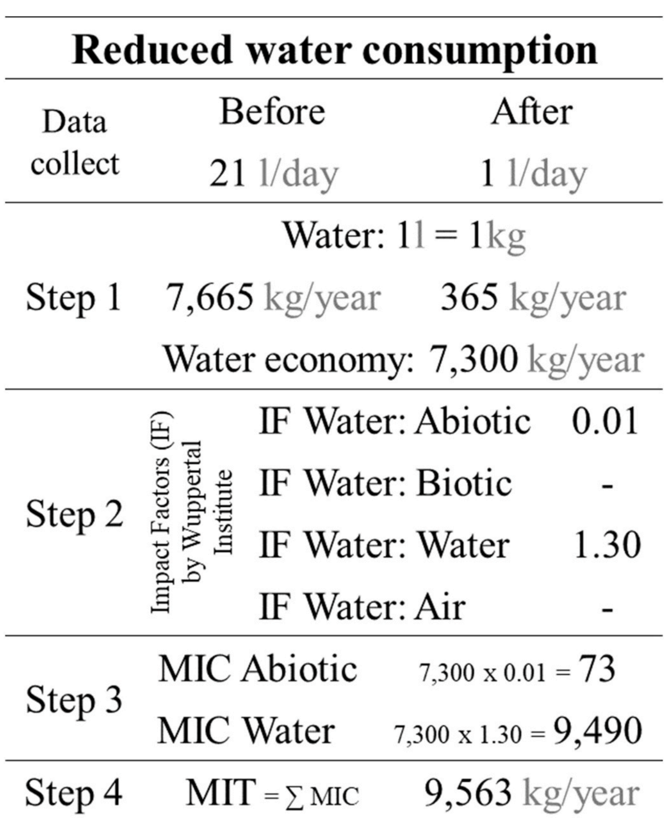

Fig. 4. Example of applying the MIF method of quantifying environmental impacts.

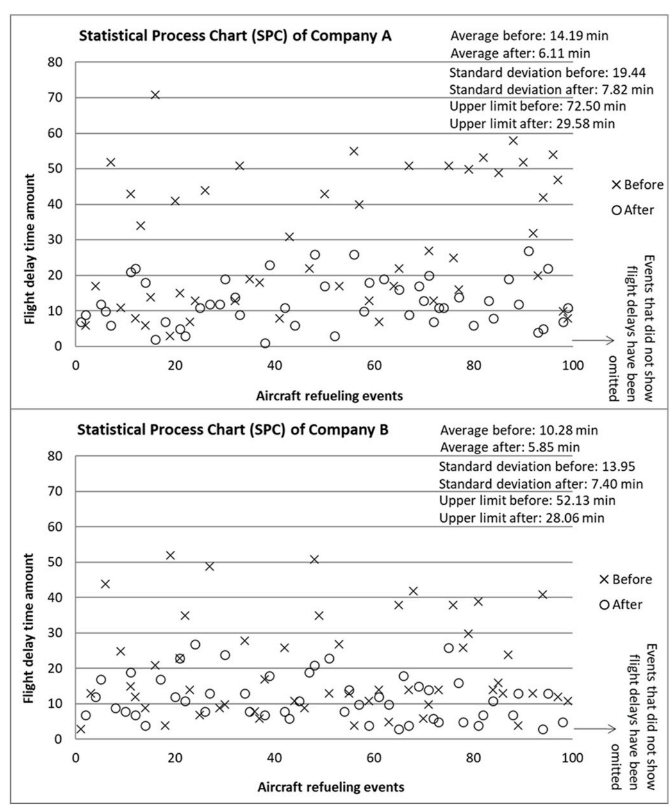

Fig. 5. Statistical Chart of the Flight Delays Process for companies A (top) and B (bottom) (adapted from Ref. [30]).

Table 2
Data on the reduction of flight delays through the application of six sigma tools in the aircraft fueling process.

Elements	Airline A	Airline B	Fuel distributor	Units
Number of measurements before	100	100	–	flights
Number of measurements after	100	100	–	flights
Total time with flight delays before	1419	1028	–	min
Total time with flight delays after	611	585	–	min
Reduced flight delay time	808	443	–	min
Total time with flight delays >15min before	90.1%	70.6%	–	%
Total time with flight delays >15min after	54.0%	48.4%	–	%
Average diesel consumption of the GPU tow tractor	3.00	3.00	–	l/h
Average diesel consumption of the GPU tow tractor	0.05	0.05	–	l/min
Average consumption of diesel from the tanker	–	–	3.00	l/h
Average consumption of diesel from the tanker	–	–	0.05	l/min
Annual number of flights performed on CGH	2,05,00,000	2,05,00,000	–	flights/ year
Market share of the annual number of flights performed on CGH	44%	44%	–	%
Annual number of flights performed on CGH per company	89,17,500	89,17,500	–	flights/ year
Number of events that resulted in a fuel or oil spill before	15	8	–	events/ year
Number of events that resulted in a fuel or oil spill after	2	1	–	events/ year
Quantity of liters of water used for washing the tarmac	15,000	15,000	–	l/event
Total amount of water used before	2,25,000	1,20,000	–	l/year
Total amount of water used after	30,000	15,000	–	l/year
Total amount of water used saved	1,95,000	1,05,000	–	l/year
Average diesel consumption of water truck	1.5	1.5	–	l/h
Average diesel consumption of water truck	0.025	0.025	–	l/min

The popularization of domestic flights in the last decade together with the emergence of new airlines, resulted in a record increase in the number of flights at the airport selected. The Effluent Treatment Station has reached its maximum capacity and the airport administrator has taken the decision to encourage companies to use water resources in a rational manner, contributing with Blue Economy. Institutional communications were made, and the fees and fines increased.

The results shown in Table 2 allowed analyzing the reduction of flight delays through the application of SS tools in the aircraft supply process. In spite of the similar quantities of flights of both airlines, the application of SS has resulted in different amounts of reduced flight delays.

The economic evaluation (Table 3) refers to the reduction in the consumption of diesel of GPUs, and companies A and B have reduced the number of times that fuel or oil has been spilled into the tarmac.

Table 3
Economic Evaluation of flight delays through the application of six sigma tools in the aircraft fueling process.

Elements	Airline A	Airline B	Fuel distributor	Units
Average price of diesel	0.92	0.92	0.92	USD/l
Quantity of diesel consumed by the tanker truck before	70.96	51.40	122.36	l
Quantity of diesel consumed by the tanker truck after	30.55	29.25	59.80	l
Amount of diesel saved by the tanker truck	40.41	22.15	62.56	l
Annual amount of diesel saved by the tanker truck	36,03,562	19,75,226	55,78,788	l/year
Annual Economic Gain with diesel consumed by the tanker truck	**-**	**-**	**51,29,764**	**USD/ year**
Average GPU diesel consumption	22	22	–	l/h
Average GPU diesel consumption	0.37	0.37	–	l/min
Quantity of diesel consumed by the GPU before	471	267	–	l
Quantity of diesel consumed by the GPU after	121	104	–	l
Quantity of diesel consumed by the GPU saved	349	163	–	l
Annual amount of diesel consumed by the GPU saved	3,11,48,151	1,45,37,117	–	l/year
Annual Economic Gain with GPU diesel consumption	**2,86,41,105**	**1,33,67,056**	–	**USD/ year**
Amount of diesel consumed by the GPU towing tractor before	63.96	36.3	–	l
Amount of diesel consumed by the GPU towing tractor after	16.5	14.1	–	l
Quantity of diesel consumed by the GPU tow tractor saved	47.46	22.2	–	l
Annual amount of diesel consumed by the saved GPU towing tractor	42,32,246	19,79,685	–	l/year
Annual Economic Gain with GPU tow tractor diesel	**38,91,601**	**18,20,345**	–	**USD/ year**
Total cost of each washing of the tarmac (fee)	4150	4150	–	USD/ event
Total cost of washing before	62,250	33,200	–	USD/ year
Total cost of washing after	8300	4150	–	USD/ year
Annual Economic Gain with reduced washes	**53,950**	**29,050**	–	**USD/ year**
TOTAL ANNUAL ECONOMIC GAIN	**3,25,86,656**	**1,52,16,450**	**51,29,764**	**USD/ year**

The reduction in flight delays by companies A and B resulted in a decrease in the use of diesel-powered JET-A1 tank trucks, and economic savings of US $ 5.1 million per year were obtained for the JET-A1 distribution company.

The reduction in the use of the GPU resulted in a decrease in the use

Table 4
Environmental Assessment of flight delays through the application of six sigma tools in the aircraft fueling process.

Elements	Airline A	Airline B	Fuel distributor	Units
Total annual amount of diesel oil saved	3,53,80,416	1,65,16,812	55,78,788	l/year
Intensity Factor (IF) - Diesel - Abiotic material	–	–	–	kg/kg
Intensity Factor (IF) - Diesel - Biotic material	–	–	–	kg/kg
Intensity Factor (IF) - Diesel - Water	–	–	–	kg/kg
Intensity Factor (IF) - Diesel - Air	3.20	3.20	3.20	kg/kg
Material Intensity Total (MIT) - Diesel	11,32,17,332	5,28,53,798	1,78,52,122	l/year
Diesel density	0.85	0.85	0.85	kg/l
Environmental Gain from Diesel	**9,62,34,732**	**4,49,25,729**	**1,51,74,303**	**kg/year**
Total annual amount of water saved	1,95,000	1,05,000	–	l/year
Intensity Factor (IF) - Water - Abiotic material	0.01	0.01	–	kg/kg
Intensity Factor (IF) - Water - Biotic material	–	–	–	kg/kg
Intensity Factor (IF) - Water - Water	1.30	1.30	–	kg/kg
Intensity Factor (IF) - Water - Air	–	–	–	kg/kg
Material Intensity Total (MIT) - Water	2,55,450	1,37,550	–	kg/year
Total residual amount of oil spilled - saved	13	7		l/year
Intensity Factor (IF) - Oil - Abiotic material	3.19	3.19	–	kg/kg
Intensity Factor (IF) - Oil - Biotic material	–	–	–	kg/kg
Intensity Factor (IF) - Oil - Water	18.72	18.72	–	kg/kg
Intensity Factor (IF) - Oil - Air	1.89	1.89	–	kg/kg
Material Intensity Total (MIT) - Oil	309	167	–	l/year
Residual oil or fuel density	0.85	0.85	–	kg/l
Environmental Gain from Cleaning the tarmac	**2,55,713**	**1,37,692**	**-**	**kg/year**
TOTAL ANNUAL ENVIRONMENTAL GAIN	**96,490**	**45,063**	**15,174**	**ton/year**

of energy, and economic savings of 28.6 million dollars per year for company A and 13.4 million dollars per year for company B. Consequently, there was a reduction in the use of the GPU towing tractor with an extra decrease in the use of diesel, with economic savings of 3.9 million dollars per year for company A and 1.8 million dollars per year for company B.

The reduction in the number of fuel or oil spills resulted in a decrease in the number of times that the tarmac was washed, and consequently, a reduction in fee payments of $ 54,000 a year for company A and $ 29,100 a year for company B.

Company A's total economic savings resulted in $ 32.6 million per year, and company B's economic savings resulted in $ 15.2 million a year. The economic savings of the fuel distribution company resulted in 5.1 million dollars a year.

The environmental assessment, using the MIF technique included the reduction in the use of diesel, the reduction of energy use, the reduction of atmospheric emissions and the reduction of the use of water in the tarmac washes (Table 4). The MIF method does not directly measure waste, pollution and other negative outputs produced or saved by the SS tools application. Nevertheless, it considers that reduced inputs mitigate negative outputs as waste, emissions or pollution. MIF provides an easily comprehensible tool to measure overall quantity of resource use.

The reduction in flight delays by companies A and B resulted in a reduction in pollutant emissions from diesel-powered JET-A1 tank trucks. Environmental gains of 15.2 thousand tons of reduced inputs per year were obtained for the JET-A1 distribution company.

The reduction of reduced inputs was achieved by the decrease of burning diesel by the GPU and the reduced use of the GPU towing tractor. Environmental gains of 96.2 thousand tons per year were obtained for company A and 44.9 thousand tons per year for company B.

The reduction in fuel or oil was spills on the tarmac resulted in a decrease in water consumption and the use of the Effluent Treatment Station. Environmental gains of 255.7 tons per year were obtained for company A and 137.7 tons per year for company B.

The total environmental gains of company A resulted in 96.5 thousand tons per year, and of company B resulted in 45.1 thousand tons per year. The environmental gains of the fuel distribution company resulted in 15.2 thousand tons per year.

Therefore, the environmental gains obtained by the three companies were added in order to identify the benefits for society, the calculated total was 156.7 thousand tons of reduced inputs per year of avoided environmental impacts.

5. Discussion

The application of SS tools in the aircraft supply process made it possible to reduce the amount of flight delays for the two largest airlines operating in Brazil, improving operational performance by 57% for company A and 43% for company B. These results are in agreement with those of Tucci and Neto [30]. The reduction in flight delays enabled the economic assessment that resulted in significant financial gains for company A of 32.6 million dollars a year, for company B of 15.2 million dollars a year and for the JET-A1 distributor of 5.1 million of dollars a year. These results are in alignment to most of the studies found in the literature that account for economic benefits of the application of SS procedures [35,57,59].

The reduction in flight delays enabled the environmental assessment that resulted in environmental gains for company A of 96.5 tons per year, for company B of 45.1 tons per year and for the JET-A1 distributor company of 15.2 tons per year by assessing the minimization of environmental impacts at biotic, abiotic, water and air levels. SS tools applied to aviation generated environmental benefits related to the reduction of water use, energy and, indirectly, CO_2 in the aircraft refueling operation, so these were green six sigma projects. It is worth noting that the water savings achieved allowed the airport's effluent treatment station to return to operating within its capacity, ensuring that the treated effluents were returned to their correct destination, including being reused in other operations at the airport facilities, soon, contributing to the blue economy, as guided by Bosma and Verdegem [3], Mulazzani and Malorgio [2], Keen et al. [1], Costa et al. [11], Ding et al. [28] and Gherghel et al. [27], a subject not explored in the airline industry.

These findings also contribute to organizational practice, as other companies in the aviation sector could adopt the fundamentals of the blue economy in their operations, in addition to planning actions to reduce energy and input consumption. The result of this research also complements Qi et al. [19] and Geissdoerfer et al. [26] research that discusses the missing links between industries, the circular economy and the blue economy, as well as complements Gherghel et al. [27] and Ding et al. [28] surveys that highlight water reuse and Costa et al. [11] which addresses the rational use of energy. The improved operational performance for companies A and B in terms of reductions in flight delays of 57% and 43% respectively, minimized the use of water by 195 and 105 thousand liters per year, respectively, since the number of fuel or oil spills in the tarmac was reduced from 15 to 2 events for company A and from 8 to 1 event for company B. In this way, water savings of US $ 54.0 thousand per year for company A and US $ 29.1 thousand per year for company B, added to the reduction of environmental impacts in the abiotic compartments of 3.1 tons per year, water compartment of 390.2 tons per year and air compartment of 37.8 kg per year.

SS was adopted as a strategic tool to reduce the contamination of aquatic systems under the guidance of Bosma and Verdegem [3], Qi et al. [19], Geissdoerfer et al. [26], Jiang et al. [21], van den Burg et al. [18], Voyer and Leeuwen [22], Weir and Kerr [20], Kronfeld-Goharani [23] who mention the effort to use organizational tools to assist in the fundamentals of the blue economy. Also, the adoption of the blue economy concepts could contribute to the organizational practice because many companies adopt SS focused to obtain operational and economic gains, but the possible environmental gains remain unnoticed, further consider blue six sigma projects.

The minimization of flight delays made it possible to proportionally reduce the time that vehicles and equipment were in operation. 5.6 million liters of diesel were saved by the JET-A1 distributor company. Companies reduced the fuel consumption, and the fuel distributor saved 5.1 million dollars a year, company A 32.5 million dollars a year and company B 15.2 million dollars a year.

Entrepreneurs could adopt SS tools in the aircraft refueling operation with a focus beyond the operational gain, which in this case is the reduction in flight delay, considering mainly the minimization of the productive resources used in the process, as is the case of the used fuel by the tank truck, that is, the reduction in the time of truck stopped for refueling reduces fuel consumption resulting in economic and environmental gains.

Another relevant aspect found in this research was that the reduction of flight delays also minimized the use of energy by aircraft on the ground, reducing the operation time of the GPUs from 90.1% to 54.0% in company A and from 70.6% to 48.4% in company B, decreasing diesel consumption by 31.1 million liters per year for company A and 14.5 million liters per year for company B. As a result, economic gains of $ 28.6 million per year and $ 13.4 million per year respectively due to direct savings from GPUs use. Consequently, the companies achieved a reduction in environmental impacts, reducing the burning of diesel by 156.3 thousand tons.

6. Conclusion

The adoption of SS tools in the refueling operation of the surveyed companies, considering the fundamentals of the blue economy as a strategy, minimized the consumption and pollution of drinking water, in addition to reducing energy consumption and mitigating CO_2 emissions, generating economic, environmental and operational performance improvements.

The theoretical contributions of this research consist of: (i) first work carried out in the aircraft supply operation that adopted SS and blue economy in order to reduce flight delays, the consumption and pollution of the water used for washing fuels or oils poured into the tarmac, which generated economic gains; (ii) the balance between economic, environmental and operational gains is aligned with the fundamentals of the blue economy to promote sustainable development; (iii) concern of airline managers about the exaggerated dumping of polluted effluents and chemical contamination in the common sewage in the failures (fuel and oil spills) of the aircraft supply operation, which gradually affects the water treatment system of the city; (iv) first survey that calculated the economic gain and reduced environmental impacts from minimizing fuel consumption in the aircraft supply operation, and consequently reducing CO_2 emissions; (v) due to the decrease in the time of the APU in operation or the replacement of the use of the APU by the GPU, it was possible to manage energy consumption to minimize energy consumption, seeking energy efficiency arising from the adoption of SS tools.

Contributions to the practice are related to: (i) many managers adopt SS tools, but are very focused on obtaining operational and economic gains through the reduction of failures in their processes and the possible environmental gains go unnoticed; (ii) guides managers in the optimization of productive resources and waste - water, energy and CO_2 emissions - based on the fundamentals of the blue economy, showing a way to meet of Sustainability Development Goals (SDGs), minimizing consumption and pollution of effluents in cities; (iii) advises managers that it is necessary to evaluate all process inputs and outputs when SS tools is implemented, being important the holistic view of all processes and resources involved, in this study, for example, the improvement of flight responsiveness, made what avoids excess energy consumption with the plane stopped; (iv) clarifies and encourages managers to formulate a strategy considering the blue economy with the use of an economic and environmental assessment procedure that is easy to use and to implement in the company's daily routine; (v) share low or no investment solutions to known problems that support the transition to a low carbon future; (vi) present to society the fundamentals of the blue economy in order to stimulate pressure from consumers and followers on social networks so that companies take responsibility for the environmental impacts caused by them.

The application of six sigma in aviation with a focus on environmental benefits is a research gap available for future research. In addition, the fundamentals of the blue economy, an integral part of the circular economy, has been little explored in terms of industrial applications such as effluent treatment and reuse of treated water, as the inadequate disposal of water results in pollution of rivers and water tables, even reaching the oceans and seas depending on the location of the company [78].

Credit author statement

Henrricco Nieves Pujol Tucci and Geraldo Cardoso de Oliveira Neto Conceptualization, Methodology; Henrricco Nieves Pujol Tucci and Flávio Luiz Rodrigues Systematic Literarure Review; Henrricco Nieves Pujol Tucci and Biagio F. Giannetti Results, Henrricco Nieves Pujol Tucci, Geraldo Cardoso de Oliveira Neto and Cecília Maria Villa Boas de Almeida Discussions and conclusions

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Research on economic, environmental and operational gains from minimizing energy, water and emissions in the adoption of SS in aviation

Country	Operation	Minimization: CO_2 emissions, water, or energy	Quantitative Assessments						Qualitative Assessments				Ref.
			Operational	Used Tool	Environmental	Used Tool	Economic	Used Tool	Environmental	Economic	Operational	Used Tool	
India	Maintenance, Repair and Overhaul (MRO) Station		Reduced annual aircraft downtime by 78%.	DMAIC and TPM									[36]
UK	Maintenance, Repair and Overhaul (MRO) Station						Eliminated GBP 1,000,000 in the overall maintenance cost	VSM					[35]
India	Maintenance, Repair and Overhaul (MRO) Station									Optimization of maintenance cost	Increase the availability of aircraft and its components	5S Kanban DMAIC	[34]
USA	Maintenance, Repair and Overhaul (MRO) Station						Sales increased from USD 30 M to USD 205 M per year	Kanban, Jidoka, DMAIC					[56]
Thailand	Maintenance, Repair and Overhaul (MRO) Station									.	Improve configuration of functions to integrated policies	DMAIC BSC QFD	[55]
Taiwan	Maintenance, Repair and Overhaul (MRO) Station										Greater motivation, greater recognition, and a stronger sense of achievement	DMAIC	[53]
Nether lands	Maintenance, Repair and Overhaul (MRO) Station		Reduced Turn Around Time (TAT) to 13,13 days	VSM and DMAIC									[49]
USA	Maintenance, Repair and Overhaul (MRO) Station									Represent a more efficient financial alternative	It will be effective in identifying and reducing the number of nonconforming vane panels.	SPC	[58]
USA	Maintenance, Repair and Overhaul (MRO) Station		50% total cost reduction, reduce cycle time by 53%, increase capacity by 52%	DMAIC									[48]
USA	Maintenance, Repair and Overhaul (MRO) Station						Savings of USD 1,2 billion	DMAIC					[57]
Turkey	Flight Operation		99.954% of total system safety performance approaching 6	DMAIC and Risk Assmnt.									[38]

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Country	Operation	Minimization: CO_2 emissions, water, or energy	Quantitative Assessments						Qualitative Assessments				Ref.
			Operational	Used Tool	Environmental	Used Tool	Economic	Used Tool	Environmental	Economic	Operational	Used Tool	
			Sigma (ie occurrences per flight hour)										
China	Flight Operations										The schedule delayed must be solved. Improve the capability of making use of data correctly and more effective management.	DMAIC	[37]

5S: Sort, set in order, Shine, Standardize, sustain; BSC: Balanced Scorecard; DFA: Design for Assembly; DFM: Design for Manufacturing; DMAIC: Define, Measure, Analyze, Improve, Control; QFD: Quality Function Deployment; SPC: Statistical Process Control; TOC: Theory of Constraints; TPM: Total Productive Maintenance e VSM: Value Stream Mapping.

Country	Operation	Minimization: CO_2 emissions, water, or energy	Quantitative Assessments						Qualitative Assessments				Ref.
			Operational	Used Tool	Environmental	Used Tool	Economic	Used Tool	Environmental	Economic	Operational	Used Tool	
Portugal	Flight Operations										Reduce the subjectivity of some risk assessments and help airlines efficiently process flight data monitoring events.	SS. Level and Risk Assmnt.	[54]
USA	Flight Operations		The vertical and lateral measured errors (Standard Deviation) are 34% (or less) of the permissible error.	Two and SS analyses									[52]
Brazil	Aircraft Manufacturer										Results used to decide on the students 'approval and to guide the instructor's plan of teaching for the next classes.	DMAIC	[40]
USA	Aircraft Manufacturer		The setup time was reduced by 50%	DMAIC									[39]
Brazil	Aircraft Manufacturer		Reduction from 19 to 9.5 man-hours per	DMAIC			Annual savings of						[59]

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(*continued*)

Country	Operation	Minimization: CO_2 emissions, water, or energy	Quantitative Assessments						Qualitative Assessments				Ref.
			Operational	Used Tool	Environmental	Used Tool	Economic	Used Tool	Environmental	Economic	Operational	Used Tool	
			aircraft and reduction of energy in 60%.				USD 57 thousand						
USA	Aircraft Manufacturer		37% reduction in the number of parts and 46% of fasteners	DFA and DFM				DMAIC					[50]
Brazil	Refueling		Flight delays was reduced to 6 min, an improvement of 57%	DMAIC									[30]
Thailand	Refueling		62.3% reduction in the number of incidents involving the refueller truck	SPC									[41]
Yugos lavia	Refueling		15% reduction in manpower	Mathematical model									[31]
UK	Refueling									.	Has enabled better and fairer control of the overtime requirements	Ergonomic redesign	[47]
UAE	Baggage Handling		A reduction in the number of bags waiting to be screened up to 97.7%.	Process Flow Chart									[43]
Chile	Baggage Handling		The results show a 65% reduction in cargo connection delays	DMAIC									[42]
Singapore	Warehouse Management		Reduced recurring shipments by 40% and saved 71 man-hours	DMAIC							Develop the Production Improvement Model with Continuous Improvement		[44]
Taiwan	Aerospace Manufacturing Supplier											TOC VSM DMAIC	[45]
Korea	Product Development										Performance of air vehicles operating in transonic flow regimes	Design for SS (DFSS)	[46]

5S: Sort, set in order, Shine, Standardize, sustain; BSC: Balanced Scorecard; DFA: Design for Assembly; DFM: Design for Manufacturing; DMAIC: Define, Measure, Analyze, Improve, Control; QFD: Quality Function Deployment; SPC: Statistical Process Control; TOC: Theory of Constraints; TPM: Total Productive Maintenance e VSM: Value Stream Mapping.

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