COVER PAGE

DEVELOP A SUGGESTIVE REVERSE SUPPLY CHAIN MODEL FOR RECLAMATION OF AVIATION OILS IN INDIA

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Aviation Management

By
Asheesh Shrivastava

November, 2020

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DECLARATION

I declare that the thesis entitled '**Develop a Suggestive Reverse Supply Chain Model for Reclamation of Aviation Oils in India**' has been prepared by me under the guidance of **Dr Prasoom Dwivedi**, Professor at Department of Economics and International Business, School of Business, University of Petroleum & Energy Studies, **Dr Saurabh Tiwari**, Associate Professor at Department of Transportation, School of Business, University of Petroleum & Energy Studies and **Gp Capt (Dr) VRS Raju**, Indian Air Force.

No part of this thesis has formed the basis for award of any degree or fellowship previously.

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CERTIFICATE

I certify that **Asheesh Shrivastava** has prepared his thesis entitles '**Develop a Suggestive Reverse Supply Chain Model for Reclamation of Aviation Oils in India**', for the award of PhD degree of the University of Petroleum and Energy Studies, Dehradun, under our guidance. He has carried out the work at the Department of Economics and International Business, School of Business, University of Petroleum & Energy Studies, Dehradun.

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ABSTRACT

As the Indian economy grows in scale and strength it's dependency on imported crude is increasing proportionally. Amongst the crude distillates, lubricating oil is the costliest. Indian refineries during 2017-18, processed 254.3 Million Metric Tonnes (MMT) of crude to produce 1.03 MMT of lubes against a domestic demand for 3.8 MMT (MoP&NG, 2019). This shortfall was made good by importing lubricants worth over ₹ 9,500 Cr (Department of Commerce, 2018).

The raw material used for producing mineral base lubricating oil is crude petroleum oil. Lubrication oil (sometimes referred to as 'lubes') is just one of the many distillates or components that are derived from crude petroleum oil in large refineries. It is further processed to remove unwanted chemicals, metals, and compounds in the fractionating towers and passed through several layers of ultrafine filters to remove remaining suspended impurities. Thereafter, the oil is mixed with a package of additives to obtain the desired physical properties (such as its ability to withstand low or very high temperature or pressure). Standard additives' package includes metal compounds such as antioxidants, anti-wear additives, viscosity index improver, metal deactivators, etc (Dr Y Khare, 2015).

Unlike fuel, lubricants are not consumed, only their properties degrade during regular usage. Used Oil can be recycled as base-stock to produce new products or used as fuel in cement/ brick kilns (Isah, 5 July 2013). Whereas improper and unsafe disposal of used oil degrades the environment, contaminates underground water, pollutes soil, destroys vegetation and threatens life on earth

including the marine ecosystem. Many countries have conducted Life Cycle Assessment (LCA) studies on used oil to evaluate its impact on the environment and formulate policies for its reuse (Giovanna, 2011). Inputs from LCA studies also indicate large ecotoxic footprint of the oil industry, motivating formulation of policies for its reuse and reclamation. Presently, the reclamation of used oil is a globally accepted practice (US Department of Energy, 2006). Research into innovative technologies have established the expanding potential of used oil and recognised reclamation of used oil as a formidable method for replacing the dwindling stocks of lubricants while concurrently reducing its carbon footprint. Germany leads in collecting and recycling of used oil (Prof. K. R. Chari T. a., 2013).

As India consumes large amounts of lubricants, it obviously generates an equally large amount of used oil, indicating a vast potential for the oil and lubricant reclamation industry. This research work discusses the method for increasing the collection of waste lubrication oil, especially that generated by the aviation sector. It proposes a reverse supply chain model which is based on principals of LCA and green supply chains. It also aims at suggesting policy changes for improving the post use management of used lubricants for enhancing its reclamation potential.

This research reasons that reclamation of used oil will not only minimise import, reduce waste generation but also provide strategic depth for the sustainable economic growth of the domestic oil industry. The intrinsic (organisational) and extrinsic (regulatory) policy changes required for maximising collection and optimizing the reclamation supply chain are also deliberated in this thesis.

Role of Lubricants in Aviation sector

Aviation oils are hydrocarbon fluids that are used in aircraft for its operation. They serve as power transmitters, lubricant, coolant, etc. Most of these oils are derived from petroleum-based feedstock which is naturally occurring and consists of complex mixtures of various other minerals. India is largely dependent on imported crude oil and base oil mix, to meet its domestic requirement of aviation grade lubrication oils (MoP&NG, 2019). According to the market research firm, Ken Research Pvt Ltd, most high end lubricants in India are either imported directly as branded product or supplied by Indian companies by blending imported additives to base-stock produced by Indian refineries (Ken Research, India, 2013).

Engine Oil used in aero-engines and hydraulic oil used for power transmission gets contaminated during flying operations. The contaminants include undesirable oxidation products, degraded additives, sediments, worn out metallic particles and condensed water vapour. This leads to decline in important physical and chemical properties of oil like viscosity, specific gravity, flash point and Ph value. These impurities remain suspended in oil until they are flushed out or drained off the system during scheduled servicing (Volkan PELİTLİ, 2014).

Aviation oil is replaced during scheduled periodic servicing because of degradation and decline in its quality or during break-down maintenance procedures. It is estimated that the Indian aviation sector including the military operators purchased over 7 lakh liters of oil during 2016-17 (Tender by Classification, 2016-17). Technically, during routine flying operations an aircraft consumes (burnt-out) only about 3-8% of engine oil and about 1-3% of hydraulic oil. Additionally, about 5-10% of the total in-use quantity may also be lost in handling, transportation and other maintenance related activities. Therefore, from above estimates, about 80% of fresh lubrication oil procurement annually, is returned to store as waste oil. This used oil is usually stored alongwith other types of automotive oils and thereafter sold as scrap. Experts profess that, if all the drained-out aviation oil is systematically collected and returned to store; in ‘as-is’ condition collected from aircraft, atleast 60% of used oil can be reclaimed as fresh base-stock. (Chari KR, 2013)

Oil Reclamation Industry

A number of commercially viable methods for reclamation and recycling waste oils are available in India. Reclamation is a process of removing impurities and additives from waste oil so that it can be reused as base-stock for producing new stocks of lubricating oil. From the perspective of Life Cycle Assessment, the reclamation process can prolong the life of natural crude oil which has not been burnt. According to US Environmental Protection Agency (EPA) reclaiming oil saves energy as well as produces fresh stocks of virgin (base-stock) oil (Managing Used Oil Advice for Small Businesses, November 1996). Following advantages for reclaiming used oil has been listed by the agency.

- ✓ Reclamation of used oil takes only about one –third the energy required for refining fresh crude oil to lubricant quality oil.
- ✓ It takes about 42 gallons of crude oil, but only one gallon of used oil, to produce 2½ quart of new, high quality lubricant oil.
- ✓ The used oil from one oil change can contaminate 1 million gallons of fresh water, which is equal to about one years' supply for 50 people.
- ✓ One litre of unprocessed waste oil still contains about 9,300 KCals of heat energy if used as fuel in brick kiln.

Worldwide, reclamation and recycling of used oil is an accepted fact in automobile industry. European and North American nations use recycled oil as base oil to meet atleast 40% of their domestic oil requirement. Very strict government regulations are in place for lifecycle management of oil for Industrial as well as Domestic users. For example, ‘British Columbia’ recycles approximately 74.6% of its oil through strict regulations and public awareness programs (Association, 2014). As per UN Environment Program studies on oils, France collects about 78% of used oil, out of which 42% is re-refined. Whereas, Germany recovers 94%, with 41% reclaimed as base-stock (Prof. K. R. Chari T. a., 2013). On the same scale, India collects and processes only about eight lakh KL of lubricant annually, which is only about 25% of its estimated waste oil generation. (Chari KR, 2013)

Status Report: Oil Reclamation in India

According to Indian government data, till the year 2016, the oil recycling industry had not matured enough, in terms of volumes, to reprocess all the domestic used/ waste oil generated by domestic industry (MoEFCC, 2016). One of the reasons deliberated by earlier researcher was lack of an established logistic chain for proper collection and resupplying oil to reclamation plants (PK Selvi, 2013). Further, inputs from industry experts (Dr Y Khare, 2015) also suggests lack of general awareness amongst technicians, worker, and consumer about the requirement for proper disposal of used oil. This had led to enormous revenue losses for industry and environmental hazard for public at large. The reasons for this dismal collection of used lubricants for reclamation can be broadly listed as under: -

- ✓ Lack of public awareness.
- ✓ Poor enforcement of regulations on safe disposal.

According to statistics provided by Ministry of Petroleum and Natural Gas, since the year 2008-09 there has been an exponential increase in cost of imported crude oil, coupled with a constant rise in domestic demand. The Ministry of Environment and Forest, first issued guidelines for recycling/ re-processing of selected group of wastes in year 2010 which included used oil under Hazardous Waste Rules 2008 (MoE F& CC). The same year, the Central

Pollution Control Board also granted licenses to about 250 small/ medium recycles to re-process waste/ used oil. Further, environmental considerations regarding the conservation of resources also boosted interest in recycling of used oil. In-spite of regulation, procedures, licences and directions, the reclamation of lubricants in India did not matched up to world standards. Today, India is the 4th largest consumer of Crude Oil after US, China and Japan, but imports much more 'lubrication oil' than even Japan since year 2016, probably due to poor reclamation.

The report on Waste Oils prepared by International Environmental Technology Centre, UNEP, India projects that Aviation Industry consumes atleast 10% of total Lubrication oil sold annually (Prof. K. R. Chari T. a., 2013). Industry experts also suggest; that due to inherent maintenance standards in aviation, the collection efficiency in the sector could be about 90% (due to good handling and accounting framework) with re-generation factor upto 70% (due to low collateral contamination). Therefore, aviation industry may alone be capable of re-generating about seven lakh litres of good quality fresh oil. This waste oil can be reclaimed at much lesser cost if it is managed and handled properly (Dr Y Khare, 2015).

In India independent private collectors, aggregate used oil from automotive service centres, industries, aircraft MROs, etc. These individuals, usually collects about 2000L of used oil daily and further sell it to bigger contractors. Some level of cleaning and segregation of oil takes place at this level. Heavy sediment oil waste is sold as 'fuel' to brick kilns and as 'lubricant' to small scale industrial fabricators. The bigger contractors fall under the category of organised sector. They are in direct contact with the oil-recycler. Most oil recyclers in India re-filter the used oil and sell it as heavy industry lubrication oil. Only few recyclers reprocess or reclaim the waste oil to produce fresh base-stock.

Study of the industry practices in India also brings out that there is an urgent need comprehensively review the management of lubricant oil by: -

- ✓ Increasing awareness and participation of aviation technician
- ✓ Enforcing regulations and
- ✓ Developing a reverse supply chain for transporting of used oils.

Valuable outline on managing/ handling used oil for small businesses like fleet maintenance facilities, MRO‘s, etc is given in US Environmental Protection Agency's (EPA's) code of federal Regulations, part 279. The agency further strongly advocates that it is very important to segregate oil at source as well as at drain-off point so as to ensure safe reclamation. EPA advices that used oil should not be mixed with any other waste. Mixed used oil becomes a hazardous waste. Handling/ re-refining/disposal of such oil requires a lengthy and costly process. Therefore, it should be ensured that used oil is segregated type-wise and batch-wise the moment it is drained after use.

The regulation of waste management in Europe and North America has fostered creation of processes and activities that ensured establishment of reverse logistics system (RLS) with strong fundaments. The formulation of concepts, tools and regulation process has ensured better Life Cycle Management of Waste oil with wide spread gains. The reverse logistics chain has also ensured development of specific knowledge about oil management, transportation, disposal and value adding skills that has improved the economic viability of the whole process.

In the Indian context, the maintenance activities in aviation industry are fairly well organised. As they are governed by strict procedural regulations enforced by organisations like DGCA, FAA and aircraft equipment manufacturers. Therefore, issues dictating waste management can be implemented with greater ease. The literacy, training level and general awareness of Aviation Technicians is much more than and other maintenance set-up. Therefore, the issues brought out above can be addressed comfortably if the higher-level managers are taken onboard this program. The only issue that need attention is the setting up of a robust Reverse Supply Chain to ensure proper collection, safe transportation and its effective integration with the reclamation process. The reverse supply chain for aviation oils requires knowledge of collaborative re-processing systems; legal frameworks and technologies that are environmentally friendly. Thus, the design of such chains will involve much more than the activity of merely transportation of waste from the MRO to reclamation plant. Finally, the reclamation will also use technologies that allow the reinsertion of reclaimed oil back into the refining and blending stage.

The Research

In order to extend the life of aviation oil and reduce cost of import of fresh base stock by the nation, this thesis explores the enabling environment to reason the economic gains. Although recycling and reclamation has been permitted by the government, it has not received the impetus that it deserves. The recycling sector is still informally organised and insufficiently supported.

This research is an effort to map the various factors that influence the collection of waste oil for reclamation in India. The thesis also evaluates various supply chain models and then suggests a customised design for used aviation oils. The details of various reverse supply chains for polluting products, referred to while designing the broad framework are explained at Chapter 3. The study is based on inputs from industry experts and academician of eminence in the field of supply chain. The researcher also recommends measures to improve the collection of used aviation oil which can, generate ancillary revenue for the industry, reduce countries dependency on import as well as reduce pollution.

As the first objective, in-depth studies of the existing procedures and practices for the disposal of used aviation oil in India were conducted. Primary data for this was collected by the researcher using surveys, schedules and interviews. Domain experts, including senior managers and shop floor level workers were contacted to comprehend the existing practices. Thereafter, a map was drawn, of the various functionaries involved in the handling of used oil. The responsibilities of each such functionary was also marked in the network. On the basis of these inputs a reference framework of nodes and interlinking dependence were designed. This network represented the existing reverse supply chain of used oil from its journey from the aviation MRO (workshop) to disposal point. Which was incineration point in most case.

The second objective was to compare the above network with various reverse supply chain models suggested by academicians, and being commercially used by industry for reclaiming ‘end-of-use-return’ products. The total cost of transportation and reclamation was also factored into while designing the theoretical model. The comparison brought out the missing node and primary reasons for low responses to oil reclamation in India.

The performance of each node and its influence on the efficiency of network was evaluated using the Analytical Hierarchy Process (AHP). For this feedback was taken from the aviation industry experts, environmentalist, academicians and supply chain professionals by circulating a detailed questionnaire. The results of the scenario evaluation technique were used to optimize and validate the suggested model. Thereafter, the economic impact of the suggested model was analysed using ‘transportation problem’– a quantitative technique from operation research.

Reverse Supply Chains

The concept of reverse supply chains for scrap and waste materials like metal scrap, waste paper, packing material, soft drink bottles, etc, have been in vogue across many countries for long. The primary reason for this being that recycling is far more economical than disposal. Secondly, concerns for the environment have also promoted the inclusion of many items in the list of ‘reusable'. Globally, waste reduction efforts have incubated the idea of developing CLSC which streamline collection of used items and integrate it with forward SC.

For example, the total paper recycled in Europe, during 1994 was only 27.7MMT. Thereafter, evolution of RSC concepts gave rise to new material flow system i.e. from the user back to the producers, which greatly increased the recovery of recyclable waste. By 2000, paper collection in Europe increased by over 70% and recycling of glass grew by 10% to more than 07 MMT (European Commission, 1997). Similarly, Netherlands reused 46% of all industrial waste (Central Bureau of Statistics, 1997). Presently, regulations in Germany mandate a recovery of 60-75% for packaging materials, transportation case, etc. The success of this concept of reuse, was attributed to consumers’ awareness, stringent legislations and a supportive ecosystem.

FMCG manufactures also introduce ‘take-back policy’ frequently, to boost sales. This marketing concept not only provides financial gains to consumers for returning/ replacing their old/ used products, but also compels retailers and manufacturers to invest in reclamation/ recycling RSCs. Such chain starts from the point of sale and end at the recycler, reclaimer or tier-II re-user.

Changing the end-point of the products supply chain from the consumer to the products’ ‘end-of-useful life’ reclaimer; presented an opportunity to extend the life of products, conserve resources, prevent waste and generate additional revenues. Such reverse supply chains also create jobs in the logistics, remanufacturing, reclamation and recycling industries.

Characterizing RSC for Used Oil

Drawing inferences from the various reverse supply chain models (Patricia Oom do Valle, 2009), advancement in re-manufacturing technology and consumers' awareness about using environment friendly products, there is a need to include used lubes in the list of recyclable products in India. The first comprehensive research paper suggesting a reverse logistics model for management of used lubricants was presented in 2010 at the Production and Operations Management Society Conference, Canada (Marcos DG, 2010). The life cycle flow of lubricants suggested by Marcos is shown in figure 1. The conference paper recommended the introduction of authorized oil gatherers and re-refiners as enablers for establishing the reverse supply chain of used oil.

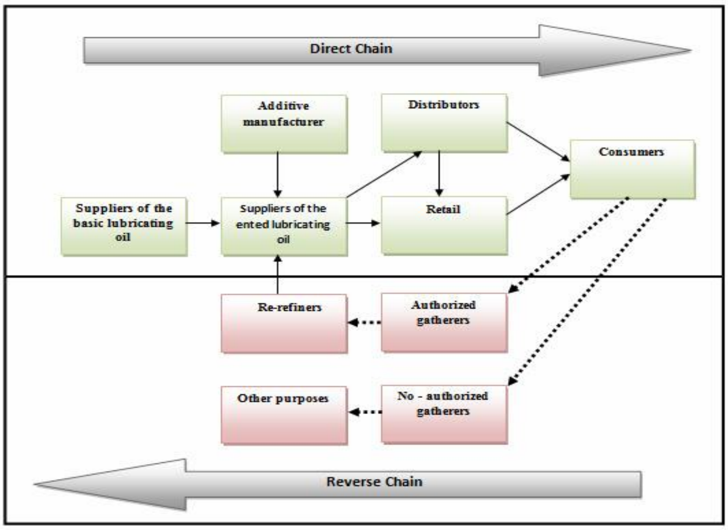

Figure 1: Direct & Reverse Chain for Lubes
Source: (Marcos DG, 2010)

The re-refining efficiency of the chain was dependent on the collection capacity of the authorized gatherers. The Hazardous Waste Rules-2016 of India has similar limitations. While there exists adequate facilities for processing used oil in India (Central Pollution Control Board, Oct 2018), the logistics chain, which connects waste generators to re-refiners, is loosely organized. Therefore, a new CLSC, with new nodes, designed to optimize collection of used lubes was proposed.

Presently, the entire process of collection of used oil is highly unorganized and loosely regulated in Indian transport sector. No formal method for collecting, sorting, transporting or reclaiming used oil exists in this sector. Although, disposing/ discharging used oil into landfill or open area is prohibited, there is no method to check or monitor the quantities of used oil drained from a single transportation unit, be it automobiles, railway engines or even aircraft. There is no (or very limited) financial incentives for users or floor level technicians to maximize collection of used oil for reclamation. Therefore, large quantities of valuable lubricant are either mixed with other type of liquid waste material and sold as scrap, reused by tertiary users without proper re-refining or disposed in drains/ landfills. While the first method of disposal may sometime lead to reclamation, the latter two approaches not only damages the operating machinery and equipment but also contaminates the environment. Accordingly, the key issues affecting collection identified during primary research included; awareness amongst consumers/ operators/ floor level technicians, regulation/ policies on accounting/ storekeeping, methods of safe handling/ transportation, remuneration for industry/ user, etc.

Enhancing Throughput for better remuneration

Similarly, in the Indian aviation industry, there is no formal method for collecting, sorting, transporting, quality control or reclaiming used aviation oil. Although, disposing/ discharging used oil into landfill or open area is prohibited, there is no method to monitor the disposal action of used oil drained from aircraft. Therefore, large quantities of valuable aviation quality lubricants are mixed with other types of liquid waste material and disposed as scrap. This leads to contamination of used oil which reduces the recyclability of the used oil. The existing life cycle flow chart of aviation lubricants is shown in figure 2 (in dotted box). The aero-lubes are produced from base-stock and after extensive quality checks is filled on aircraft. After completing its designed life or on failing quality standards it is drained out as used oil. This oil is disposed 'off' as scrap for incineration or drained into landfills.

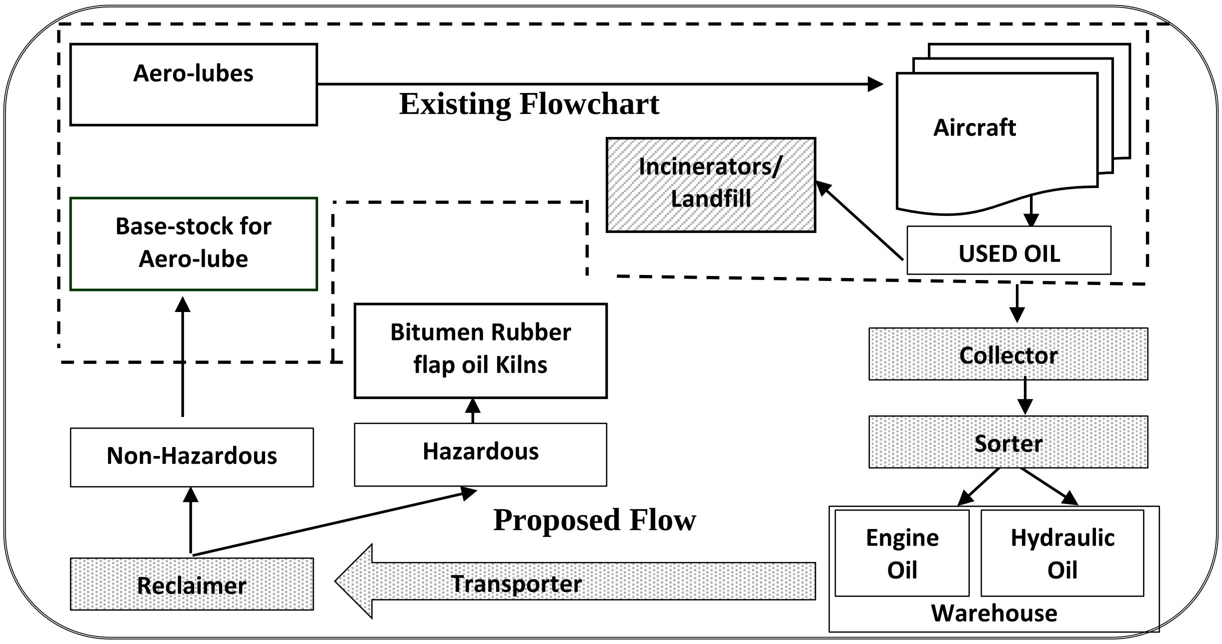

Figure 2: Suggested Life Cycle of Used Oil with Functional Nodes

However, on introducing the following independent functional nodes in the flowchart, the life cycle of used oil can be enhanced.

(a) Collector. Is directly responsible to ensure proper collection of used oil drained from the aircraft/ equipment. The quantities of oil drained out/ collected are to be documented in the aircraft log-book/ maintenance records by the collector.

(b) Sorter. Is responsible for the sorting and safekeeping of different grades of oil. Required to maintain and manage the inventory of used oil until handed over to the transporter.

(c) Transporter. Is responsible for proper transportation on used oil from warehouse to reclaimer. Required to maintain records as mandated in Hazardous Waste Rules 2016.

(d) Reclaimer. Is responsible to ensure use of appropriate environmentally safe technology for reclaiming aero-lubes. Ensure maximum recovery of base-stock which can be used to make new stocks of lubricants, also required to ensure proper disposal/ use of hazardous waste.

For this research it was evident that collection/ collector is the most important node in the recovery chain at organisational level. The collection margins depend on the efficiency of the collector. Internal policies/ regulations are essential to direct individual for adhering to organisational goals. Provisioning of specialist tools and availability of transportation kits, training for technicians, storekeeper and users are other important organisational issues which would decide the quality and quantity of used oil recovered by the system. Internal audit of purchases and recoveries is essential to rate the efficacy of policy and level of acceptance by the system. Financially reclamation of used oil is at-least three times more gainful than its unsolicited disposal into landfill or reclamation as automobile oil.

Key Takeaways

Result of SWOT (Strength Weakness Opportunity and Threats) analysis which map the opportunities and challenges for the used oil reclamation industry in India is illustrated below.

Strength	**Weakness**
The forte of used oil reclamation industry have been its ability to (a) Reduce pollution (b) Reduce import and encourage re-processing	Issues that discourage expansion and penetration of reclamation industry are: - (a) Requires additional energy to re-process

activities in the domain of MSME sector (c) Encourage economic activities and skill development in supply chains for collection of used oil (d) Re-refining used oil takes only about one-third the energy required for refining fresh crude oil	(b) Requires investment in Environmentally Safe Technologies (c) Labour intensive in collection & transportation activities (d) Additional documentation. (e) Additional penalty for disposal of waste generated in the reclamation process.
Opportunities (a) Offers growing prospects to produce energy and useable product from waste. (b) Increase in industrialisation and expansion of transportation sector reflects increase in consumption of lubricants and concurrent expansion of reclamation industry for used oil. (c) Lower investments as compared to large refineries. (d) High demand for finished product. (e) Large saving in forex.	**Threat** (a) Used oil categorised as Hazardous Waste may require skilled manpower and specialised equipment for handling and transportation (b) Availability of raw material not guaranteed due to loosely established collection supply chains (c) Conflict with illegal market for used oil reseller (as branded product) (d) Conflict with unauthorized use as furnace oil (for heating)

After detailed analysis of the industry problem, research gap and analysing the variables, this thesis also makes certain policy recommendations for aircraft Maintenance and Repair Organisations (MRO) which could help them generate additional revenue from used oil and also reduce their carbon footprint. The research also suggests few changes to the May 2016 policy, 'Hazardous and Other Waste (Management and Transboundary Movement) Rules of the Ministry of Environment, Forest and Climate Change, Government of India.

At national level, it is important to ensure strict compliance to Hazardous Waste Rule 2016. There is a need to include the disclosure of purchase and consumption pattern by each consumer so that correct estimation of waste generation can be made. Presently, only disposed quantities are being acknowledged in the quarterly returns by industry. Therefore, there is no traceability of handling losses and in-house wastages. Concurrently, there is also a need to introduce mandatory use of reclaimed oil along-with fresh oil for all new formulations. There should also be a total ban on import of used/ waste oil, which adds to pollution and also suffocates domestic oil reclaimers towards investing in and strengthening localised supply chain. Similar policy approach is being followed in many developed/ developing countries of European Union and North America.

Further, the reclaiming used oil will prove atleast three times less expensive than buying new stocks of fresh base oil. If the same arithmetic is extrapolated to the entire automobile and industrial sector, the savings would be exponentially high. From a user perspective, added remuneration for collecting used oil will incentivise individuals to put-in efforts towards returning drained oil. While, as a nation, reclamation of used oil will save valuable forex, 1/3 rd of 1541.16 M USD or ₹ 3,340 Cr annually on import of lubrication oils. If the cost of environmental damage is added to these calculations, the saving to the nation would be many times more beneficial and justify focused efforts in this direction.

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Asheesh Shrivastava

Dedicated with reverence

to

My Father

Late Shri Vijay Kumar Shrivastava

And

to

the sweet memories of

Late Dear Pratiyogita Shrivastava

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CHAPTER 1

INTRODUCTION

1.1 Lubricants Industry: An overview

As the Indian economy has grown in scale and strength over the last two decades, it's dependency on imported crude has increased proportionally (RBI, Mint Street Memo, 2019). The crude distillates, include fuel like LPG, Petrol, Diesel, Kerosene, etc and lubricating oil. The last is the costliest product of the refining process as very limited quantities are produced. According to the American Petroleum Institute, while 44 percent of the product is petrol and 21 percent is diesel, only 1 percent is lubricating oil. In fact, lubrication oil is the most valuable distillate of crude both according to quantity as well as quality. The figure 1 shows the distribution of various distillates of crude. Indian refineries during 2017-18, processed 254.3 Million Metric Tonnes (MMT) of crude to produce 1.03 MMT of lubes against a domestic demand for 3.8 MMT (MoP&NG, 2019). This shortfall was made

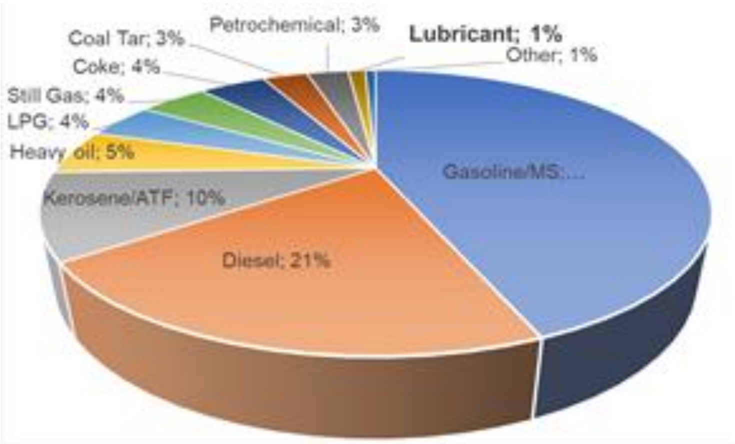

Figure 1: Distillates of crude (US Energy Information Administration, 2019).

good by importing lubricants worth over ₹ 9,500 Cr (Department of Commerce, 2018).

The raw material used for producing mineral base lubricating oil is crude petroleum oil. Lubrication oil (sometimes referred to as 'lubes') is just one of the many distillates or products that are derived from crude petroleum oil in large refineries. It is further processed to remove unwanted chemicals, metals, and compounds in the distillation columns or refineries and circulated through several layers of ultrafine filters to remove remaining suspended impurities. Thereafter, the oil is blended with a number of additives to obtain the required physio-chemical properties (such as its ability to perform satisfactorily even at extremely low or high temperature or pressure). Standard additives' package includes metal compounds such as antioxidants, anti-wear additives, viscosity index improver, metal deactivators, etc (Dr Y Khare, 2015).

Unlike fuel, lubricants are not consumed, only their properties degrade during regular usage. "Used Oil can be recycled as base-stock to produce new products or used as fuel in cement/ brick kilns" (Isah, 2013). Whereas improper and unsafe disposal of used oil degrades the environment, contaminates underground water, pollutes soil, destroys vegetation and threatens life on earth including the marine ecosystem. "Many countries have conducted Life Cycle Assessment (LCA) studies on used oil to evaluate its impact on the environment and formulate policies for its reuse" (Giovanna, 2011). Inputs from LCA studies also indicate large eco-toxic footprint of the oil industry, motivating formulation of policies for its reuse and reclamation. The reclamation of used oil is a globally accepted practice (US Department of Energy, 2006). Research into innovative technologies have established the expanding potential of used oil and recognised reclamation of used oil as a formidable method for replacing the dwindling stocks of lubricants while concurrently reducing its carbon footprint. Germany leads in collecting and recycling of used oil (Chari, 2013).

“Reclamation and recycling of used oil is an accepted technology in industry worldwide. European and American nations use recycled oil as base oil to meet at least 40% of its domestic oil requirement” (Dr Y Khare, 2015). For example, “British Columbia recycles approximately 74.6% of its oil and Germany re-collects over 94% of used oil with 41% being reclaimed as fresh base-stock” (US Department of Energy, 2006). In some countries this has been achieved through improvement in technology, firm implementation of environmental regulations and user awareness.

As India consumes large amounts of lubricants, it obviously generates an equally large amount of used oil, indicating a vast potential for the oil and lubricant reclamation industry. This research work discusses the method for increasing the collection of waste lubrication oil, especially that generated from the aviation sector. It proposes a reverse supply chain (RSC) model which is based on principals of LCA and optimised using AHP. The RSC is based on inputs from the Indian aviation industry. The thesis aims at suggesting a multidimensional reverse supply chain model and concurrent policies changes required for improving the post use management of used lubricants. The outflow from the research work, would enable enhancing the reclamation potential of used lubricating oil, reduce environmental damages and mitigate increase in imports.

1.2 Oil Reclamation

According to Indian government data, published in the year 2016, the oil recycling industry had access to very limited volumes of domestic used/ waste oil for reprocessing (MoEFCC, 2016). The reach of regulation was very limited as regards management of used/ waste oil generated by domestic industry. One of the reasons suggested by a researcher (PK Selvi, 2013) from the Central Pollution Control Board (CPCB) was the lack of an established logistic chain mechanism for collecting used oil from domestic users and supplying it to the reclamation industry. Further, inputs from preliminary survey of the oil market by the researcher (deliberated later) also suggested a general ignorance amongst technicians, worker, and consumer about their obligation towards controlled disposal of used oil. These limitations led to unwanted disposal of used oil resulting in low volumes of collection, revenue losses for industry, environmental hazard for inhabitant and additional burden of import. The reasons for this dismal low level of collection of used lubricants for reclamation could be attributed to two reasons, namely: -

- ✓ Lack of public awareness.
- ✓ Enforcement of regulatory mechanism on post use management of used lubricants.

According to the data published by the Ministry of Statistics (MoSPI), Government of India (Central Statistics Office, 2019), there has been an exponential rise in the demands and consumption of lubrications in India. It has risen from 2.0 MT in 2008-09 to 3.88 MT in 2017-18 with a growth rate of over 11.92% over the previous year (Central Statistics Office, 2019, p. 65). Concurrently, the import parity price of lubricants has increased by over 14% over the last eight years (Central Statistics Office, 2019, p. 80). This has led to increased out flow of foreign exchange to meet nation's demand for lubricants.

Earlier, the technical guidelines on recycling and re-processing of certain group of wastes were first issued by the Ministry of Environment, Forest and Climate Change in year 2010 (IL & FS, 2010). The manual discussed in details about the post use management of Hazardous Waste including used and waste oils. Thereafter, since 2010, the CPCB and various State Pollution Control (SPC) Boards have been issuing licenses to MSMEW's to carry out recycling/ reclamation of used or waste oil, using approved Environmentally Safe Technologies (EST). Presently there are over 500 registered oil reclaimer in the country (CPCB, MoEF&CC, 2019, p. 19). These efforts were driven by concerns for conserving environment and natural resources rather than the economic interests or advantages of recycling used or waste oil. Data on waste generation/ collection accessed from the website of CPCB (CPCB, MoEF&CC, 2019), suggest that, in-spite of promulgation of a numbers of regulations, policies and licenses the reclamation of lubricants (in terms of quantity) is abysmally low in India. According to these reports for the year 2017-18, the capacity utilisation of oil recycling/ reclamation industry was only 31% (CPCB, MoEF&CC, 2019). Today, India is still the 3th largest consumer of lubricants (Lindemann, 2018), probably, due to its poor record of being able to recycle used oil.

1.3 Worldwide Practices

The demand for lubricants are driven primarily by rapid industrialisation and increased use of automobiles. However, it is not always easy to meet these increasing demands due to depletion of crude reserves which can provide good quality lubricants and cost of producing fresh lubricating base oil (Mikael Höök, 2014). Therefore, shortages in supply of fresh base-oil, high demand for lubricating oil and concern for environment have motivated many industries to seek and adopt ways to regenerate/ recycle lubricating oil (Isah, 2013) (Zambiri, 1988). Considering the environmental and economic ill effects of improper handling of waste/ used oils many countries have enacted various legislations to govern and promote recycling/ reclamation and safe disposal of waste oil. Therefore, governments across the globe have enacted legislations to govern and promote recycle/ reclamation and safe disposal of waste oil (ATIEL Used Oil Technical Committee, Mar 2009). The policies on the management of used oil of various countries are tabulated below: -

Sl No	Country	Used Oil Management Program
1	France	According to US, Dept of Energy, France had targeted to ensure 78% collection of used oils from all users under a government-funded programs since 1999. An additional fee was also imposed on virgin lubes producers. By year 2005, over 42% of used oil was being re-refined by refiners under the directions from the government (US Department of Energy, 2006).
2	Germany	According to government data, Germany collects approximately 41% of used motor oil from users and service industry, due to a very high level of consumer interest in recycling. The remaining 35% is incinerated in cement kilns, and 24% processed or burnt in other applications. All oil retailers are required to provide collection facility near their establishment; retailers are required to pay for used oil pick-up. The reclamation industry recovers about 94% base stock from used oil, thus, recovering about 48% of total lube oil sold in the country (US Department of Energy, 2006)
3	Italy	In Italy, government regulations mandate the use of re-refined oils in motor oils. Re-refining plants are funded by lube oil sales taxes, while the oil collectors and re-refiners are subsidised. Only 10% of total used oil collected can be incinerated in cement kilns (US Department of Energy, 2006). The collection efficiency of used oil was 48.7% in 2009. (Giovanna, 2011). There are specific tax incentives like 50% rebate in excise duty is granted for use of re-refined product as compared to virgin lubricant. These tax rebates are granted only if the used oil is sourced from domestic users.
4	Australia	The government provides high tax subsidies for re-refining domestic used oil. The quantum of subsidies reduce for low grade burning oils; while none for reclaimed industrial oils. It is estimated that the country collects over 81% of used oil drained from various users (US Department of Energy, 2006).

Sl No	Country	Used Oil Management Program
5	United States	The United States encourages recycling of used oil as a national policy. Some states in US impose additional taxes so that collection cost can be subsidised. Few states have also classified used oil as hazardous waste, thereby making dumping or open disposal, illegal. Local municipalities also fund oil collection activities. These initiatives have produced positive results in reducing improper disposal of oil; encouraging the small re-refining industry; disposal of used oil as a fuel. The US has a mandatory federal policy requiring the purchase of re-refined oil, thus promoting the reduction in fresh oil and recycling of materials including disposal under the Resource Conservation and Recovery Act and Pollution Prevention Act" (US Department of Energy, 2006).
6	India	In year 2008, the Ministry of Environment and Forests (MoEF), and Central Pollution Control Board (CPCB), Government of India had certified various facilities across multiple states for recycling about 1.39 MMT of used oil. Licensed for reclamation was held by about 257 small-to-medium recyclers [500 Kilo Litres per Annum (KLA) to 12000 KLA] (Chari KR, 2013). Later by year 2014, India was already generating over 6.2 MMT of Hazardous Waste (HW) from 36,165 industries (MoEF&CG, GoI, 2016). It was then projected that India has a huge potential for recycling used lubricating oil and this is likely to increase further with the increase in oil consumption by the automotive, power and manufacturing sectors. Under the 2016, Hazardous Wastes (Management, Handling & Transboundary Movement) Rules, the procedure for accounting of HW were finalized. The HW were differentiated based on type and source from where generated. Accounting and interstate movement of HW were streamlined. However, some difficulties still existed towards of methods of estimating quantum of HW generation by industry and individual users. Therefore, mapping, segregation and collection of recyclable items is still a constraint for waste / used oil reclaimer.

Sl No	Country	Used Oil Management Program
		Correct mapping of quantity and quality of used oil will reduce the expenditure towards the collection, transportation, storage and subsequent reclamation cost.

Table 1.1:Country-wise Policies and Targets on Management of Used oil

1.4 Managing Used Oil-Economic Consideration

Valuable information on managing and handling used oil for small enterprises (MSMEs) like fleet maintenance facilities/ MRO‘s, etc, is provide by the US Environmental Protection Agency (EPA) in its publication “Code of federal Regulations”, part 279 (Managing Used Oil-Advise for small businesses, 1996). EPA defines reclamation as a process that comprises of re-engineering used oil to eliminate physical and chemical impurities so that it can be re-used as base formulation or base oil for manufacturing new lubricating oil. The process can extend the life of lubrication oil indefinitely. Recycling ensures a closed-loop management environment for used oil by re-processing it to be the same product that it started out as. In other words, “reclaiming oil saves energy as well as fresh stocks of virgin oil” (Xavier, 2013).

- ✓ Used oil reclamation consumes only about 1/3rd the energy required to refine crude oil to make fresh lubricant oil.
- ✓ Over 190 litres of crude oil is required to produce 2.1 litres of new, high quality lubricant oil, whereas only 4.5 litres of used oil produces the same quantity of base oil.
- ✓ 3.8 million litres of fresh water can be contaminated by just 5 litres of used oil. This quantity of water can quench the thrust of 50 people for over a year.
- ✓ Over 9,300 KCals of heat energy can still be harnessed from one litre of unprocessed waste oil, if it is used as fuel.

1.5 Practices in India

Recycle or reclamation of used lubrication oil is a physio-chemical process for the removal of the contaminant or impurities, from used oil. The simplest process may include pressure filtration to remove physical impurities and chemical treatment with sulphating agents for removing aromatics and other impurities. There are many other much improved and efficient reclamation processes which have been developed for specific type of contaminated/ used oil. The CPCB with the support of MoEF&CC in India has first issued "*Guidelines for Environmentally Sound Technologies for Recycling of Hazardous Wastes"* as per Schedule IV of Hazardous Wastes (HW) Rules, 2008 in January 2010. These guidelines had approved the following Environmentally Sound Technologies (EST) for reclamation of used oil in India: -

- ✓ "Vacuum distillation with clay treatment
- ✓ Vacuum distillation with hydro-treating
- ✓ Thin film distillation
- ✓ EST processes for waste oil including centrifuging and dehydration of water and reducing the sediment to the desired level
- ✓ Any other EST other than that given in the guidelines may be adopted with the approval of Central Pollution Control Board (CPCB)"

As the demands for natural resource increased, quantities depleted, resulting in an increase in cost of raw material. As a fall back option, the demand for recycling and re-processing of selected group of waste materials increased, concurrently. These products and resources included lubrication oil from petroleum crude. Concerns for environmental damage caused by waste oil and consideration about the conservation of natural resources also boosted global interests in recycling of used oil. Few advantages of oil reclamation for India could be listed as followings: -

- ✓ Conservation of valuable oil resource due to repeated usage
- ✓ Significant saving of FOREX due to reduced import
- ✓ Reduce environmental damage and save local ecology
- ✓ Reduce burden on storage and disposal of hazardous waste
- ✓ Significant reduction in carbon foot print.

The products derived from used oil processing can be cost effective only, when sufficient quantities are available and affordable competitive technologies are in place for reclamation. Literature survey on the subject sufficiently justifies availability of affordable technology to reclaim oil. However, absence of an established reverse supply chain, that ensures availability of sufficient volumes of lubricant was missing for the Indian transport sector specially the aviation industry. In order to ensure cost advantage, the Life Cycle Approach system to support the reclamation process is required. Further, users' awareness is also very important as segregate oil at source (drain-off point), unpolluted transportation, etc. are other factors that would also affect cost of reclamation. Used oil when mixed with any other type/ grade of oil, renders it into becoming a hazardous waste, making recycling/ reclamation difficult. Re-refining such type of contaminated used oil, may require a much lengthy and costly process. Therefore, it is advised be ensure the segregation of used oil in type-wise and source-wise form, at the point of it being drained, so as to ensure cost effective reclamation.

1.6 Lubricants for Aviation sector

In aircraft, hydrocarbon fluids or aviation oils are used for flight operation, as power transmitters, as anti-friction agents and as coolant, etc. Most of these are derived from natural occurring petroleum products. These oils may also consist of a mix of various other minerals and compounds which are used to enhance their performance. India is essentially dependent on imported crude oil and base-stock oil, to meet its requirement of aviation grade lubrication oils (MoP&NG, 2019). According to the market research firm, Ken Research Pvt Ltd, most aviation grade lubricants in India are either imported directly from manufacturers or supplied by Indian companies by blending imported additives with base-stock produced by Indian refineries (Ken Research, India, 2013).

In aircraft aero-engine oil is used for lubrication and cooling while aircraft hydraulic oil is used for transmitting power. All types of oils get contaminated during aircraft operations. These contaminants include oxidised hydrocarbons, chemical sediments, degraded additives, worn out metallic particles and condensed water vapour. Presence of these undesired products effect the performance of the fluid and changes its important physio-chemical properties like specific gravity, viscosity, flash point and acidity. These physical impurities also remain suspended in the oil system until they are removed from the system during scheduled maintenance (Volkan PELİTLİ, 2014).

Aviation oil is regularly replenished or/ and replaced during scheduled periodic servicing. It is primarily due to the degradation of its properties or decline in its performance. It may also be replaced during break-down rectification or replace of associated component. It is estimated that the Indian aviation sector including the military operators purchased over 7 lakh liters of oil during 2016-17 (Tender by Classification, 2016-17). Technically, an aircraft could consume (burnt-out) about 3-8% engine oil and about 1-3% of hydraulic oil, during routine flying operations. Additionally, about 5-10% of the total in-use quantity may also get wasted or lost during transportation, handling and other maintenance related activities. Therefore, from above estimates, about 80% of fresh lubrication oil procurement annually, should be returned to warehouse as used oil. However, as a common practice, all types of used oil are stored together in common vessels and sold / disposed-off as scrap. Notwithstanding the common practice, Experts advise that, segregation of various types of used oil especially aviation oil would improve its reclamation value. As aviation oils are much less contaminated than other types of used oil. Used aviation oil could yield over 60% fresh base-stock as compared to other types of oil. (Chari KR, 2013)

From the annual tender enquires floated by defence and government owned aviation companies, it is estimated that the government controlled organisations alone annually purchases over 11 lakh liters of aviation oil including hydraulic and engine oil for aircraft use (Finance Dept, Information Technology Department GoI, 2018). Out of this only 3-8% of engine oil and 1-2% of hydraulic oil is actually consumed (burnt-out) during operations. The rest of the oil is replaced during scheduled servicing or maintenance activities. Surprisingly only about 20% of this oil is returned to warehouse as used oil and sold as waste along-with other automotive oils.

According to industry experts, “if all the drained out used aviation oil is systematically collected and returned to store; atleast 80-90% of used oil can be reclaimed” (Dr Y Khare, 2015). This used oil if managed properly can also act as a source of ancillary revenue for the airlines and signal in a green initiative towards reducing the carbon footprint of the aviation sector. As discussed earlier, there are a number of environmentally sound technologies for reclamation/ recycling used oils. Few of them could be tailored to meet the requirements of aviation sector while reducing wastage (OG Kayode Sote, 2011). “Reclamation/ recycling of used oils are an accepted fact in automobile industry worldwide. European and North American nation use recycled oil as base oil to meet at least 40% of its domestic oil requirement” (Chari KR, 2013). In India, MoEF&CC has issued regulations on management of used/ waste oil and HW generated by various industries and users. However, these rules may require certain tweaking for the Indian aviation industry.

From the national data compiled by CPCB (CPCB, MoEF&CC, 2019), it is evident that the Indian oil reclamation/ recycling industry has not been able to perform at its established capacity due to non-availability of feedstock i.e. used lubricating oil. There could be many reasons for such shortfall. Few researchers, suggests absence of a robust collection system for proper gathering and sourcing used oil to reclamation plants (Dr Y Khare, 2015). Another reason could be a lack of understanding amongst floor-level technicians and worker about the environmental obligations and benefits of proper disposal of used oil.

A scientifically designed reverse supply chain can not only help increase the collection of used aviation oil, but also identify a commercially viable and environmentally safe technology for its reclamation. The entire aviation sector can capitalize on waste generation and leverage the economic potential of used aviation oil. Further, the model can also be adapted to other sectors like, Railways, State Transport Corporations, etc, where large amount of used oil is generated at fixed interval and limited location across India.

1.7 Business Problem Statement

It is estimated that the Indian aviation industry annually spends over ₹700 Cr (inclusive FOREX for imported brand) towards purchase of aircraft grade oil. Further, unsolicited disposal of used oil adds to the carbon footprint of the sector. This brings us to the business problem that can be defined as: -

“Presently the entire range of aviation oil is either wasted or disposed-off as scrap by the Indian Aviation Industry due to non-availability of an established reverse supply chain to ensure appropriate reclamation.”

1.8 The Research Proposal

In order to extend the total intended life of aviation oils and reduce cost of import of fresh base-oil feedstock, it is proposed to develop a logistics supply chain for used oil. The supply chain would work in reverse direction to the forward supply chain i.r.o fresh lubrication oil and focus on increasing the collection and safe transportation of used oil to the reclaimer. The supply chain would also focus on identifying the best suited environmentally safe reclamation technology for aviation oils. The focus would be to formally organise the chain within the existing regulation or may recommendations for its improvement.

This research study is an effort to map the various factors that influence the collection of waste oil for reclamation in India. The study also evaluates various supply chain models and then suggests a design for used aviation oils. The details of various reverse supply chains for polluting products, referred to while designing the broad framework are explained at Chapter 3. The study is based on inputs from industry experts and academician of eminence in the field of supply chain. The researcher also recommends measures to improve the collection of used aviation oil which can not only generate ancillary revenue for the industry but also reduce countries dependency on import.

As the first objective, the research studies the existing procedures and practices for the disposal of used aviation oil in India. Primary data for this was collected by the researcher using surveys, schedules and interviews. Domain experts, including senior managers and shop floor level workers were personally contacted to understand the existing practices. Thereafter, a map was drawn, of the various functionaries involved in the handling of used oil. The responsibilities of each functionary were also marked in the network. On the basis of these inputs a reference framework of nodes and interlinking routes was designed, which would represent the existing reverse supply chain model for reclamation of used oil.

As the second objective, the model framed in the first step was validated by comparing it with various reverse supply chain models suggested by academicians or being commercially used by industry for reclaiming 'end-of-use-return' products. The total cost of transportation and reclamation was also factored while designing the theoretical model.

The performance of each node and its influence on the efficiency of network was evaluated using the Analytical Hierarchy Process (AHP). For this feedback was taken from the aviation industry experts, environmentalist, academicians and supply chain professionals by circulating a detailed questionnaire. The results of the scenario evaluation technique were used to optimize and validate the suggested model. Thereafter, the economic impact of the suggested model was analysed using 'transportation problem'– a quantitative technique from operation research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The process of removing impurities from used oil and restoring its properties, so that it can be reused as new lubricating oil is called reclamation. Hydro-cracking, solvent extraction and factional distillation are among the various established processes of reclamation. According to the US Government's – "Environmental Protection Agency (EPA)" - "reclaiming oil saves energy as well as produces fresh stocks of virgin (base-stock) oil" (Managing Used Oil Advice for Small Businesses, November 1996). The agency further exemplifies the following i.r.o. used oils: -

- ✓ Over three times more energy required for refining crude oil to lubricant oil than to re-refine used oil to useable base oil.
- ✓ It takes only 4.5 litres of used oil to produce 2.1 litres of high quality lubricant oil, while 190 litres of petroleum crude is required to produce same quantity of new oil.
- ✓ Over 9,000 K Cals of heat energy is still contained in a litre of waste oil, which can be used to fire brick kilns.

Further, the US House of Representative vide Public bill No 115-345 (US Senate - Energy and Natural Resources, 2018), has directed the US Department of Energy to regularly report to it, the environmental benefits of re-refining of used oil in the country. It is also required to submit to the US Congress a long term and short plan on methods to increase the collection of used lubricating oil and energy saved due to its reclamation. The law requires implementation of certain measures to: -

- ✓ Enhance the pooling-in of used oil
- ✓ Circulate public information and awareness on viable options for reuse of used oil
- ✓ Promote sustainable reuse of used oil by federal agencies, recipients of federal grant funds, entities contracting with the federal government, and the general public.

Reclamation of automobile oil is an established process in India and many industries have been given the licence to reclaim waste/ used oil by the Central Board of Pollution Control or State Pollution Control Boards (MoEF&CG, GoI, 2016). The technologies used for reclamation are also approved by various ministries, including the Ministry of Environment and Forests. However, data on quantities of used/ waste oil collected by each state, available in public domain (websites of state pollution control boards), it is seen that quantities collected are far less than global industry standards. Therefore, it is necessary to carry out detailed quality audit of the quantities of oil purchased by different consumers, match it with the quantity of used oil being generated by each consumer, identify plug-holes in the oil ecosystem from where used oil is being wasted/ discharged into the environment causing pollution. This data is necessary to establish the true economic potential of the oil reclamation market. Traditionally, reclamation technologies been evaluated from the perspective of environment safety. Therefore, there is a need to develop product specific technologies, especially for the high cost aviation industry in India. Finally, the most important element of reclamation eco-system is the existence of a robust collection mechanism, which is pre-requisite to ensuring economic success and damage to environment.

2.2 Search Process

Considering the above, a comprehensive spectrum of papers was reviewed in order to establish a better understanding of the topic and identify the research gap. The objective was to understand the reclamation process, benchmark the industry practices, evaluate the Indian policy framework and map the post use management of aero-lubes (lubricants used in aircraft). The aim was to identify the reasons for used oil not reaching the reclaimer and being discharged at landfills, etc. Concurrently, the various reverse supply chain models suggested by eminent scholars and industry experts were also studied. The aim was to identify the best model that could optimises the reinsertion of used oil into the aerospace industry as the fresh base stock. The scope of the search process is depicted in table 2.1: -

Key word used	**Journals/ Reports/ Compendium/ Books Explored**	**Database Examined/ Subscribed**
1. Oil 2. Lubricants 3. Reclamation 4. Petroleum production 5. Refining 6. Recycling oil 7. Reuse 8. Hazardous waste 9. Environment safe technologies	**<u>Journals</u>** 1. International Journal of Engineering and Applied Sciences 2. Computer Science & Engineering: An International Journal 3. Jordan Journal of Mechanical and Industrial Engineering 4. Logistics Information Management 5. European Journal on Operational Research 6. Journal of Supply Chain Management 7. International Journal of Engineering Research and Technology 8. Naval Research Logistics, UK	1. Elsevier 2. Science Direct 3. Research Gate 4. acedemia.edu 5. jstor.org 6. Google Scholar

Key word used	Journals/ Reports/ Compendium/ Books Explored	Database Examined/ Subscribed
10. Aviation lubricants 11. Supply chain 12. Reverse logistic network 13. Green Supply Chain 14. Aviation management 15. Life Cycle Assessment 16. Close loop Supply Chain 17. Lubricant import 18. Oil additives 19. AHP 20. AHP for supply chain	9. Pesquisa Operacional, Brazilian Operations Research Society 10. Journal of Operations and Supply Chain Management 11. International Journal of Production Research 12. Journal of Remanufacturing 13. Imperial Journal of Interdisciplinary Research 14. European Journal of Operational Research 15. Production Planning & Control 16. Procedia Environmental Science 17. International Journal of Busisness Science & Applied Management 18. Journal of Business Logistics 19. International Journal Services Sciences 20. Journal of Economic Behavior & Organization	
	<u>Database/ Annual Report</u> 1. ATIEL Used Oil Technical Committee 2. Hand Book on Civil Aviation Statistics 3. British Columbia Used Oil Management Association: Annual Report 4. Statistical Yearbook of the Netherlands 5. National Inventory on Hazardous Waste Generation & their Management, CPCB, New Delhi 6. State/UT-wise status of HW generation in the country, CPCB, New Delhi 7. The Economics of Waste and Waste Policy. London, UK 8. Conference: Operations Management in an Innovation Economy, EU	
	<u>Books</u> 1. Medium econometrische toepassingen	

Key word used	Journals/ Reports/ Compendium/ Books Explored	Database Examined/ Subscribed
	2. Compendium of Recycling and Destruction Technologies for waste oils 3. Research Methodology. New Age International (P) Ltd	
	<u>Ministry/ Department/ Committees</u> 1. Bureau of Energy Efficiency, Ministry of Power, GoI 2. CPCB, Ministry of Environment Forest & Climate Change, GoI 3. DGCA, Ministry of Civil Aviation, GoI 4. PP&AC, Ministry of Petroleum and Natural Gas, GoI 5. United States Environmental Protection Agency, USA 6. American Petroleum Institute, USA	

Table 2.1: Search Process

The research papers, articles and publication that were reviewed/ referred to have been collated under the following thematic groups in order to correctly identify the research gap, define the research problem and devise the research methodology.

- ✓ Theoretical Understanding of Oil and Reclamation Process
- ✓ Policies and Regulations on Management of Used Oil
- ✓ Oil Reclamation: Technology Overview
- ✓ Reverse Logistics Supply Chain-Recycle/ Re-use
- ✓ Indian Oil Reclamation Industry: An overview
- ✓ Use of Analytic Hierarchy Process (AHP) tool

2.3 Underpinning Theoretical Understanding of Reclamation

According to experts (The Petroleum Refining Industry, 1999), almost every lubricant used today is derived from natural base oil or produced from synthetic ester. The American Petroleum Institute (API) defines the methodology of classification of lubricants. It categorises the base oils into five categories and are listed in Appendix E of API 1509. All industrial petroleum based lubricants are produced by blending one or more of these API groups/ base stock oil with property enhancing additives. The institute also suggests that almost all types of used oils can be reclaimed as fresh oil or burnt to recover a large amount of latent energy. Thereafter, in 2003, the "United Nations Industrial Development Organisation (UNIDO)", along with International Centre for Science and High Technology prepared a "Compendium of Used Oil Regeneration Technologies" This well researched book strongly advocates for better management of used and waste oils and technology options for reclamation/ regeneration of the same (F. Dalla Giovanna, 2003). The report suggested that waste oil is almost totally reusable, even if it derived from different sources or blended for different uses. For example, waste automotive oil can be mixed with industrial oil for the reclamation process. Volkan and Ozgiir, (Volkan PELİTLİ, 2014) researched waste oil samples taken from multiple supersonic military aircraft operating in different conditions and investigated for the following criteria: content of Arsenic, Cadmium, Chromium, Lead, Polychlorinated Biphenyls, Chlorine and halogens and also the flash point. The results obtained from the analyses indicated that the heavy metals were well below the maximum permissible limits for material recycling making them safe for reclamation. This and other similar research have demonstrated the possibilities of reclaiming all types of used lubricating oil. Analogous views were also expressed by many oil experts such as Isah AG (Isah AG, 5 July 2013), Prof. K. R. Chari (Chari KR, 2013), Winslow H Herschel and AH Anderson (Winslow H Herschel, 1922), Hala M Abo-Dief, and Ashraf T. Mohamed (Hala M Abo-Dief, December 2014)

The method for recovering valuable components like complex esters from high performance oil synthetic based lubricating oil compositions was also described by Alfred H Matuszak (Cranford, USA Patent No. 2857421, 1958). Now-a-days, many types of lubricants are produced by synthetically blending the mineral oil derived base stock with complex additives to obtain or enhance specific properties/ characteristics, according to application. Similar opinions have been expressed by many other eminent authors. Recent research has presented new and advanced methods to reclaim different types of oil. However, the post-use reclamation process is the same for most commercially marketed industrial lubricating oils that are derived from mineral crude. From an exhaustive review of reclamation technologies, it is evident that used aviation oil can be reclaimed like any other commercial lubricant. However, no specific research on post use management of used **aviation** oil has been carried out. It is, therefore, opined that if a specific study on commercial exploitation of used aviation oils is carried out, the increased ancillary remuneration and associated reduction in environment pollution would justify the investment in new technologies. The study could further exemplify and define policies and procedures on post-use management of used oil.

The table 2.2 summarizes the work of various studies on the subject: -

Sl No	Source	Author	Research Takeaways
1.	"Reclamation of Used Synthetic Lubricating Oils"	Alfred H. Matuszak (Cranford, USA Patent No. 2857421, 1958)	The paper describes the methods to reclaim used synthetic oil. The process can also be used for aviation oil
2.	"Reclamation of Hydraulic Fluid"	Warren McMordie and George Petrovich, (San Diego, USA Patent No. 3098826, 1963)	The paper describes a new method to reclaim used hydraulic oil. The process can also be used for aviation oil
3.	"Measurement and standards for used Oil-II"	US Dept Commerce NBS (National Bureau of Standards, 1977)	The US certification agencies alongwith engine manufacturers specify engine oils which can to be used on aircraft. Only application wise qualified /certified oils can be used in aircraft. As regards base oil to be used in the formulation, it
4.	"Aeroshell Turbine Engine Oils Handbook"	USAF Turbine Engine Oils, Manual (Aeoshell)	

Sl No	Source	Author	Research Takeaways
			does not differentiate between fresh and reclaimed oil.
5.	“Reclamation of Syn Turbine Eng Oil Mix”	Glasgow, Gerald; Richard J (Glasgow, 1979)	The paper describes a new method to reclaim used synthetic oil. **The process can also be used for aviation oil**
6.	“The Petroleum Refining Industry”	Industrial Energy Use (The Petroleum Refining Industry, 1993)	The paper lists the various methods of refining petroleum products and energy consumption of the industry. The data from the paper is used for bench-marking purpose.
7.	“Compendium of Used Oil Regeneration Technologies UN Industrial Developmental organisations”	F. Dalla Giovanna, S Miertus (F. Dalla Giovanna, 2003)	The paper suggests that Waste oil is almost totally reusable, even if it derived from different sources or blended for different use. For example, the waste automotive oil can be mixed with industrial oil for reclamation process.
8.	“Reclamation and refortification of hydraulic fluid”	Hydraulics & Pneumatics (Rob Profilet, 2008)	The article provides valuable insight to benchmarking the reclamation. Due to this fact, expensive aviation oil is mixed with cheap automobile oils for purpose of reclamation. If both are treated separately the quantities recovered would be exponentially higher
9.	“Virgin and recycled engine oil differentiation: Spectroscopic study”	Mohammad A. Al-Ghouti and Lina Al-Atoum (Md A Al-Ghouti, 2010)	The paper maps the qualitative deterioration of oil during its life cycle. However does not address the specific aviation oil.
10.	“Compendium of Recycling & Destruction Technologies for Waste Oils”	Prof. K. R. Chari (Chari KR, 2013)	India specific paper published under the aegis of UNEP, containing detailed analysis of post use disposal of lubrication oil. But does not address the specific need of aviation oil
11.	“Regeneration of Used Engine Oil”	Isah, A. G., Abdulkadir (Isah AG, 5 July 2013)	The paper describes a new method to reclaim used oil. However, the paper is silent on whether the process can be used on aviation oil.
12.	“Characterization of waste oils	Volkan PELİTLİ, Özgür DOĞAN1	The paper illustrates that, reclamation of military lubricants

Sl No	Source	Author	Research Takeaways
	in air-breathing jet Turbine engines”	(Volkan PELİTLİ, 2014)	can restore original base-stock properties of oil and the distillate waste oil will contain high concentration of minerals therefore this can be used as fuel in cement/ ceramic kilns.
13.	“Waste Oil Recycling Using Microwave Pyrolysis Reactors”	Hala M. Abo-Dief, (Hala M Abo-Dief, December 2014)	The paper suggests an alternate “microwave pyrolysis method” for reclaiming used engine oil. The process is a green approach for safe treatment and re-refining of automobile oils.
14.	“Used Oil and Re-Refining- Fuels and Lubricants Handbook”	G. Totten, R. Shah, and D. Forester (Totten, 2019, pp. 29-38)	This chapter includes a brief history of re-refining; terminology germane to the industry and list out various test methods and their significance in the assessment of used oil quality. The book is included in the US nation manual for testing and standards

Table 2.2: Theoretical understanding of reclamation process

2.4 Policies and Regulations on Management of Used Oil

The unsuitable ways of disposal of used oils in landfill and waterbodies has emerged as a major cause of environmental damage across many nations. Therefore, to reduce such damages, it is essential to have an environmentally sound waste oil destruction policy to halt further damages. Various countries have instituted benchmarking audits to estimate the quantity of waste oil generated and ways to improve its collection. Many countries have also formulated strict regulations on handling of waste oil. These models have successfully reduced the demands for import/ production of fresh lubrication oil. During 1975, a study at the Temple University, Philadelphia, Penn. (U.S.A.) by John A. Sorrentino of the Department of Economics and Andrew B. Whinston, Purdue University (U.S.A.) (John A Sorrentino Jr, 1975) presented an integer-linear programming solution to “The Economic Implications of Recycling Exhaustible Natural Resources: the Case for Crude Oil”. The paper presented a decision model which analyses the problems relating to the likely increase in demand for products made from recycled oil versus those made from virgin oil base. Especially when these decisions are weighed against, balance-of-trade problems and the cost of contamination of the environment. The paper reasons that societies will have to make a choice between the abovementioned three decision parameters. While the cost of exploration and production of fresh oil will continue to escalate over time, the cost of recycling may reduce with improvement in technologies. Therefore, there would be increasing benefits to society to invest in reclamation. The theoretical model presented in the paper evaluates the inputs constraints and examines the potential gains. Thereafter, the model suggests ways in which governmental agencies can optimise the cost and quantity of production of fresh oil by satisfying the three variables i.e. Demand, Balance of Trade and Pollution. Accordingly, policy-makers have started to consider reclamation of oil as one possible method to reduce energy crises and pollution.

For example, the British Columbia’s (BC) Used Oil Management Association, which is a non-profit Society in British Columbia, South America, started incentivising since 2011, collectors and recyclers if they ensured that used oil, discarded oil-filters, antifreeze and cast-off oil containers are collected and managed well (BC Used Oil Management Association, 2013). Thereafter, collectors across British Columbia started picking up the used oil and antifreeze materials from more than 4,000 generator points and delivering them to the society’s registered processors, where these items were processed so that they could be sold as raw material for remanufacturing oil. Later, the society reported that over 75% of fresh oil in BC was safely recovered in the year 2013 (Bourgeois, 2013).

Similarly, in 2003, Shing Tet Leong and Preecha Laortanakul (Shing Tet Leong, 2003, Vol 15, No 6) presented a survey on consumption of lubrication oil in Thailand and analysed the collection and re-refining procedures prevalent at the time. As a case study, the paper gave a detailed narration of the oil collection practices in Bangkok. It then referred to the various regulations on management of used oil prevalent in the country as compared to those in the USA. The paper suggested that the collections of used oil can be wilfully improved by modifying a few laws and ensuring their implementation. According to the author, two laws (a) Hazardous Substances Act - 1992 (HAS); and (b) Fuel Oil Storage Act - 1931, of Thailand presently govern the management of used oil in the country. However, the authors opine that the existing legislation cannot effectively improve collection as its outreach is limited. Therefore, they recommended a new law specifically addressing oil collection and recycling. They also suggest regulations to standardise the technologies that could be used to harness the known potential of the used oil, being traded in the markets of Bangkok.

Concurrently, Dennis W Brinkman (Brinkman, 1987) has also presented a paper comparing the various oil recycling processes in the USA and tabulating the cost effectiveness of each of these technologies. These technologies are discussed later in the subsequent chapters. Kun Guo of the University of Stavanger, Norway, Department of Petroleum Engineering, and Hailong Li of the Mälardalen University, Sweden, Department of Energy, (Kun Guo, 2015), researched Nanotechnology as a new and path breaking in-situ technologies for oil recovery. According to the authors, the increase in global energy demand has focussed attention on re-utilising used/ waste heavy oils to generate power. A number of technical approaches have been proposed for the recovery used oil in the paper, for successful regeneration of heavy base oil containing hydrocarbons. It is also mentioned in the research paper that many of the new technologies consume large quantity of power/ energy and release huge quantities of waste water, thereby becoming environmentally taxing themselves. In the opinion of the authors, the use of metal-based-nanoparticles for reclamation of used oil has unlimited advantages both financially and environmentally.

Similarly, Michel Bourgrois explains that the quantity and quality of waste oil collected is an important consideration in the overall strategy (Bourgeois, 2013). This paper also states that aviation oil can be a major source of waste oil if the system is well established. The paper carries out a survey of waste oil production and collection in California. It then uses the Life-Cycle-Assessment (LCA) method to audit the post use management of used oil, including that generated by aviation sector. The data for analysis was sourced from the California Integrated Waste Management Board, USA. Likewise, MA Usman and OG Kayode carried out studies on used oil reclamation in Nigeria (OG Kayode Sote, 2011). They concluded that one of the most environmentally friendly way of dispersing waste oils is reclamation of oil using the 'Fullers Earth Method' which can also be a reliable method to create wealth from waste. The chemical process and results of these experiments are discussed in detail in the research paper. In India, a team of academicians and students from Acharya Nagarjuna University, Guntur, researched on technologies to reclaim used engine oil (Md Touseef Ahmed, 2015). The team used the solvent extraction method, alongwith sulphuric acid and active carbon, for recycling waste oil. The process suggested by the team produced recycled engine oil whose characteristics and physical properties like the flash point, fire point and viscosity were identical to those of fresh engine oil.

A Gureev, MI Falkovich, Yu Evdokimov and V Samikh, have discussed about a centralised collection and reclamation system for used oils in the erstwhile USSR (A Gureev, 1985). They proposed for the establishment of oils collection centres across the country where used oil is segregated according to its type. The collection centres could be designated as MMO (Mixed Motor Oils) and MIO (Mixed Industrial Oils) group. Under this pooling system, the primary sorting could be undertaken during the collection stage itself and only the secondary processing would require to be performed at specialised plants. The paper debates on the virtues of primary sorting, and exemplifies its advantages through scientific analysis. According to the authors, with pre-sorting, both the quality and quantity of fresh base-stock recovery is much better. A similar collection sorting process could be developed for aviation oils for better commercial gains for the aviation sector. This approach was, therefore, researched in greater details. The same is explained under para 2.6.

Recently, the Defence and Security Accelerator (DASA) the research and technology wing of Royal Air Force, (UK) announced a £1M funding for the development of a pioneering technology. The innovation should be able to reclaim used aviation grade oils and lubricants (Defence And Security Accelerator, Min of Def, 2020). The R&D institute believes that these efforts would help the Armed Forces save considerable sum of money in waste disposal charges. At the same time, the process would deliver an environmentally-friendly by-product which could save petroleum resource. In the year 2019, the development contract was conferred to few universities and engineering firms. Under the contract, they were required to demonstrate that the new technology could recycle hydrocarbons from used oil and use it to produce new valuable by-products. The aim of this R & D project was to demonstrate RAF's intension to decarbonise defence operations.

Some other recent research papers on reclamation processes and management of used oil is shown in table 2.3 below: -

Sl No	**Source**	**Author**	**Research Takeaways**
1.	"British Columbia Used Oil Management Association"	Oil Report (BC Used Oil Management Association, 2013)	The audit report is a bench marking tool which can be replicated in India. Does not mention the quantities of aviation oils reclaimed
2.	"Used Oil Mgmt: International Exp & Approach for Colombia"	Michel Bourgrois (Bourgeois, 2013)	The paper presents the results of survey of various local policies on the management of used oil.
3.	"Failure Analysis and Regeneration Performances Evaluation on	X. L Wang, (XL Wang, 2013)	The results of the study can be used to design a reclamation process for Indian aviation Industry and minimizing waste generation.

Sl No	Source	Author	Research Takeaways
	Engine Lubricating Oil”		
4.	“Metallic nanoparticles for enhanced heavy oil recovery: promises and challenges”	Kun Guo, (Hailong Li, 2015)	In this article, the author provides an overview of nanoparticle technology which can enhance recovery of heavy oil. A similar process can be used to design reclamation of aviation oils in India.
5.	“Concentration of heavy metals in virgin, used, recovered and waste oil: a spectroscopic study”	Munirah Abdul Zali, (Munirah Abdul Zalia, 2015)	The results of the study can be used to design a similar reclamation process for Indian aviation oil.
6.	“Recycling and Analysis of Spent Engine Oil “	Md Touseef Ahamad, (Md Touseef Ahamad, 2015)	The study suggests a more economical way of regenerating spent oil, the process can also be used to reclaim aviation oils
7.	“Polymeric surfactants for enhanced oil recovery: A review”	Patrizio Raffa (Patrizio Raffa, 2016)	
8.	“MoD allots fund for innovative waste oils recycling technology”	James Heappey, DASA, MoD (Defence And Security Accelerator, Min of Def, 2020)	The research presented to DASA, substantiates the understanding that used oils and lubricants discharged from military aircraft can be re-refined using microbes and converted to re-usable products

Table 2.3: Regulations on used oil management

2.5 Oil Reclamation: Technology Overview

In recent years, issues concerning the exploitation of natural resources and their detrimental effects on environment has furthered public interest in reclamation. Technical developments especially those underscoring waste recovery, have fuelled interest in recycling of petroleum products. Improved ecosystems of some developed countries, have endeavoured at satisfactorily meeting up to

50% of its need of lubricants through recycled oils (Chari KR, 2013). Different countries use different technologies for maximizing recycling of used oils. Recent research has also demonstrated that over 85% of desiccated used oils can be transformed into useful by-products with the use of appropriate technology. Most of the by-products of reclamation process include base oil, for making lubricating oils and fuel for use in brick kilns. Re-refining is complicated process. This is because used oils could be sourced from over 500 different commercial grades and 1,500 varied formulations. The basket of used oil encompasses release from applications ranging from automobiles to aviation to industries and to marine users. New lubricants are increasingly becoming more and more complicated in formulations. They are being designed to be functionally diverse and therefore contain more complex additives. The performance enhancing additives in modern lubricants sum up to 30% or more by volume. Such oils are therefore difficult to recycling using conventional reclamation methods. Therefore, segregation of various grades/ make of oil is advised for greater recoveries. Mixed lot of used lubricants are difficult to reclaim.

As per a study sponsored by the United Nations (Chari KR, 2013), few drivers' may be necessary for any developing technology to be economically successful in addressing the demands of the ecosystem. These include, use of Environmentally Sound Technologies (EST), ability to ensure consistency in quality and quantity, capability to process diverse feedstock and ability to ensure release of minimum hazardous waste.

The recycling capability of used oil to be regenerated as fresh base-stock is very closely linked to the contamination level and type of impurities present in the drained oil. The technology for reclamation is also dependent on the original composition of oil, type of additives, and application. The oil reclamation industry is over five decades' oil in US and Europe, using a variety of technologies and specialising in specific class or variety of used oil. In America itself there are over 200 registered oil reclaiming companies, producing re-refined oil or fuel for variety of applications. There are also about 20 re-refiners in Europe and over 4000 oil re-refining plants worldwide, using various technology. Globally the used oil reclamation capability is over 1.8 million tonnes/year with a market size of over 4,106.7 Mil USD in 2017 for Europe (Transparancy Market Research, 2019). Potential suitability of reclaimed lubricating oil to be used across variety of application including its original user has already been established by many researchers. Provided reclamation is carried out by proper segregation, clean-up and chemical treatment. Reclamation and re-refining used oil also removes certain carcinogenic compounds which get generated in oil during its fair use. Industrial research also supports the fact that reclamation of used and waste oil makes it safe from being a toxic effluent. To regain products usefulness, it may require to be processed through multiple steps.

The selection of correct reclamation process depends on various factors which may include the type of base-oil used while formulation the lubricant. The origin of used oil, its contamination level and the quality requirements of the finished product also influence the selection of right technology. Most reclamation technologies still produce about 4% to 4.5% of dehydrated hazardous waste. The dangerous waste consists of heavy metals, Polycyclic Aromatic Hydrocarbons (PAH) and other chemical compounds.

Oil re-refining processes have also witnessed great technological advancement and upgradation, especially with regards to improvement in yield and reduction in environmental impact. However, limited progress has been made in India as regards developing specific technology for reclaiming aviation oils. The reasons for these are discussed later in this thesis. However, before deliberating further on the technology part, availability of raw material (used aviation oil) also needs a close review. The collection mechanism for reusable/ recyclable items like used oil is discussed in the subsequent section.

2.6 Reverse Logistics Supply Chains: Re-cycle/ Re-use

The idea of reuse of certain industrial material and household waste like paper, packing material, metallic scrap, plastic/ glass/ PET bottles, etc are been effectively managed by users and reclaimer since the turn of this century. The principal motivation for this could have been the understanding that reuse/ recycle/ reclaim of waste was far more economic and rational than its disposal in landfills. The concerns for the environmental impact of used products had also encouraged inclusion of many more articles into the list of ‘recyclable' items. Universally, developing reverse supply chains for reusable products has become a vastly researched topic. The waste reduction efforts based on life cycle impact assessment and green solutions have incubated recycling efforts that merge the forward supply chain with recycling policies. While, reverse supply chains for scrap and waste materials have been in vogue across the globe, in different formats, realistic commercial data on its collection, segregation and reclamation have been available only towards the end of the last century. For example, the first reliable data on total paper collection for recycling in Europe, is available only since 1994 and was estimated to be about 27.7 million tonnes (A Shrivastava, 2017).

However, few years later consumer responsiveness towards environment assisted with user-friendly collection and trading system ensured an increase in assortments by over 70% annually (European Commission, 1997). According to the data recently released by the European Paper Recycling Council (EPRC), in the year 2017, the paper recycling rate in EU had reached 72.3%. The council published that 59.6 million tons of paper was collected for recycling against a consumption of 82.5 million tons (paperforrecycling.eu, 2018). Europe has declared to targeted recovering 74% of the total paper consumption by 2020.

Similarly, according to the European Container Glass Federation (FEVE), the recycling rate for glass containers had reached 73% in 2015. With a closely monitored Closed Loop- Circular Economy Business Model, over 25 billion glass containers were recycled during the period (FEVE, 2015). Likewise, Germany recovers between 60% to 75% of packaging material, while the Netherlands reuses about 46% of industrial waste (Central Burea of Statistics, 1997). These are few demonstrative examples in which the flow of material from users, back to the manufacturer has been smoothened and enhanced with effective use of concepts of reverse logistics.

Improving consumers' awareness about the damaging effect of waste disposal, and establishment of an effective supply chain has greatly increased the recovery of recyclable waste (Gobbi, The Reverse Supply Chain: Configuration, Integration and Profitability, 2008). Thereafter, the management of this branch of supply chain management which deals with the physical flow of material opposite to the orthodox forward supply chain is termed as "Reverse Logistics" (Tomasz DOMGAŁA, 2013). It has now developed into an extensively researched field.

In the last decade, many papers have been written on the concepts and use of RSC for improved operation. Volumes of study material are also available on various theories and models of the reverse supply chain (Dr. Devendra S. Verma, 2016). However, most papers of these papers address the needs for the automobile and apparel industries, where the items are required to be withdrawn from the retailer end and sent to workshop for rework or repair. A few papers also address the requirements of the reverse supply chain for Information Technology (IT) hardware, which is treated as hazardous waste. In these scenarios, apart from the cost, time is also an important criterion. Detailed review of various reverse supply models is discussed in Chapter 3 on Reverse Supply Chains.

As regards the specific requirements of the aviation industry, till date, the focus of most researchers has always been on improving the functioning of the forward supply chain. These robust chains are required to support the seamless supply of spares to sustain the on-time commitments of this sector. The reverse supply chain for recyclable spares and other items has not received the required attention (Larsen & Jacobsen, 2015).

Further, commercial and flight safety considerations have always demanded a fast-responding spare support system to sustain global operations. Traditionally, time has been amongst the most important concerns of the forward supply line of the aviation sector. One of the best examples being, V Benjamin Yen's paper on "Aviation Spare Parts Supply Chain Management Optimisation at Cathay Pacific Airways Ltd", published in 2009 (Yen, 2009). According to the author, forward supply chains for aircraft spares is multifaceted as it is needed to serve a highly distributed user base with large variety of spares. At the same time the network should comply with stringent quality and regulatory requirements of the industry. The paper suggests establishment of an 'Aeroxchange Market Place' where all the spares could be commonly held. The store inventory could be shared among the various commercial airlines, equipment manufacturers and repair agencies. Such a set-up would greatly reduce the inventory stocking cost of airlines and also the downtime/ repair time of each item/ spare. Similarly, Daglar Cizmeci has examined the "supply chain management practices of the Boeing Commercial Airplane Company" in relation with the global aircraft industry (Cizmeci, 2005). The paper published by the researcher has brought out that changing concepts and practices of supply chain in the aerospace industry has led to development of large base of Tier I and Tier II suppliers by Boeing. Spares from these suppliers have to be distributed globally to sustain the requirement of aircrafts. Another research by the Massachusetts Institute for Technology (MIT) on the aerospace supply chain management, suggest Lean Aerospace Initiative for supporting spares network. The paper brings out in great detail the supply chain network model of the aviation industry. However, the paper does not cover the aspect of movement of unserviceable spares for repair or the reverse supply chain in the aviation industry (YEN, 2009).

In the considered opinion of the researcher, there is also a need to study and model the reverse supply chain for repairable spares and other products like batteries, tyres, used furnishing, etc of the aviation sector, from the economical as well as environmental perspective. This gap has been discussed in this research work. Some recent research papers on reverse logistics supply chains are shown in table 2.4 below: -

Sl No	Source	Author	Research Takeaways
1.	"Designing the reverse supply chain: Impact of the product residual value"	Chiara Gobbi (Gobbi, Designing the reverse supply chain: Impact of the product residual value, 2011)	The paper studies the impact of the "Product Residual Value (PRV)". It also analysis the loss of value with time i.r.o. returned products in the RSC
2.	"Reverse logistics network design: a holistic life cycle approach"	Joanna Daaboul (Joanna Daaboul, 2014)	The paper explains that RL network is supported by activities: collection, sorting, gate-keeping, and recovery (disposal) with example of the IT hardware.
3.	"Determining the total cost of reverse supply chain operations for original equipment manufacturers"	Larsen, Samuel (Larsen & Jacobsen, 2015)	The paper suggests that the Total Cost of the RSC is made up of cost of dismantling, refurbishing, component refitting and disposal of recycle materials.
4.	"Stochastic multi-objective optimization approach to redesign the sustainable reverse supply chain network for plastics recycling"	Michael Feitó (Michael Feitó Cespón, 2016)	The paper proposes a stochastic multi-objective model for sustainable RSCs. It illustrates the model with a Cuban case study based on recycling of plastics. For purpose of optimizing sustainability the decisions parameters in the model include material flow design and transport balance in accordance with location of each facility.

Sl No	Source	Author	Research Takeaways
5.	"Supply chain forecasting when information is not shared"	Mohammad M. Ali, (Mohammad M. Ali, 2017)	The papers discuss the concept of "Downstream Demand Inference (DDI)" phenomenon, where the downstream demand is inferred by the upstream members of the supply chain in the absence of a formal information sharing mechanism. This paper, evaluates a simple DDI strategy based on Simple Moving Average (SMA) method. Thereby allowing mathematical inference of consumer demand and cutting inventory costs.
6.	"An engine oil closed-loop supply chain design considering collection risk"	Mohammad Mahdi Paydar, (Mohammad Mahdi Paydar, 2017)	This paper studies the collection and re-distribution of used engine oil. Mixed-integer linear programming model for a closed-loop supply chain is used to optimise the model.
7.	"Supply chain collaboration in industrial symbiosis networks"	Gábor Herczeg (Gábor Herczeg, 2018)	The paper suggests the development of industrial symbiosis (IS) model, in-line with concepts of circular economy to achieve economic benefits. The earning can be enhanced with effective utilization of waste by-products.
8.	"Literature review: Strategic network optimization models in waste reverse supply chains"	JensVan Engeland (Jens Van Engeland, 2018)	The paper considers environment and social performance indicators for designing multi-objective RSC models. It also considers the effect of factors like extended producer responsibility schemes, circular economy challenges, etc in

Sl No	Source	Author	Research Takeaways
			designing complex strategic networks.
9.	"Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review"	Md Tasbirul Islam (Md Tasbirul Islam, 2018)	Reverse Logistics supply chains form part of many waste management process. The paper evaluates the types of RL based on its design, plan for inverse distribution framework and performance evaluation system.

Table 2.4: Reverse Supply Chain models

From the holistic review of published literature of reverse supply chains it is evident that while reverse logistics supply chains are a highly researched subject, very limited work has been conducted on optimising the logistics for collection of used lubrication oils in India. Low volumes of collection could be one of the factors for low recoveries (reclamation) of used oil. This has resulted in higher imports of lubricants and base stock oil for the country between 2011-2018 (Export Import Data Bank Commodity: LUBRICATING OIL , 2020).

2.7 Indian Oil Reclamation Industry: An overview

Since the year 2006, the Government of India has been instituting various measures to encourage the reclamation of waste oil. As different industries use different types of oil, the management of oil for each sector has its own problems and, therefore, require tailored model to improve the efficiency of collection and reclamation i.r.o. each sector. Therefore, sectorial research/ studies need to be carried out to reduce India's dependence on imports. As far as the aviation sector is concerned, very limited primary source data on the consumption pattern of oil/ aero lubes is available. Further, literature on post use management of aviation oil is restricted within the operational set up on the industry. Therefore, a need to carry out a scientific study to estimate the quantity of used oil generated by the aviation industry and thereafter, suggest a logical model for enhancing its recyclability/ reclaim-ability was felt by the researcher. This will not only reduce the carbon footprint of the Indian aviation sector but also generate ancillary revenue for it.

Some research papers and articles on oil reclamation efforts in India are listed at table 2.5 below: -

Sl No	Source	Author	Research Takeaways
1.	"Technology options in oil reclamation"	Chemical Business (LAWPSP Symposium, 2007)	The paper highlights the efforts of MoEF in promoting reclamation of waste oils in India. It also discusses the various reclamation techniques approved by GoI.
2.	"Re-Refining of Used Automotive-Lubricating Oil: Setting up a Demonstration Unit for Studies on Reclamation"	Dr RP Badoni (UPES, 2011)	The paper includes the proposal for setting up a small oil reclamation plant at UPES university campus.
3.	"Carbon Footprint of Indian Aviation"	Directorate General of Civil Aviation (DGCA, 2012)	Ground breaking study to map the environment effect of aviation. The paper does not address the impact of unsolicited disposal of waste oil.
4.	"Compendium of Recycling and Destruction Technologies for Waste Oils"	Prof. K. R. Chari (Chari KR, 2013)	An exhaustive status report prepared for the UNEP. It gives details of India's used oil management policies/ regulation as in 2010

Sl No	Source	Author	Research Takeaways
5.	“Spent oil management and its recycling potential in India-inventory and issues”	P K Selvi (P K Selvia, 2013)	The paper highlights the efforts of MoEF in promoting reclamation of waste oils in India and identifying the existence of a gap in reclamation targets especially in lubricants and oils. The paper also discusses the problems faced by the reclamation industry like; Cost of the collection, warehousing and transportation, etc
6.	“Reducing the exploration and production of oil: Reverse logistics in the automobile service sector”	Bhaskar B.Gardas (Bhaskar B.Gardas, 2018)	The paper identifies and analyse the reverse logistics problems faced by the industry while handling used automobile oil. These barriers include insufficient government support, organisational limitations, limited commitment of management to environment issues, etc
7.	“Preliminary Comparison Among Recycling Rates for Developed and Developing Countries: The Case of India, Israel, Italy and USA”	Francesco Di Maria (Francesco Di Maria, 2019)	Paper compares the recycling rates for waste in countries like India, Israel, Italy and USA. And suggest the following reasons for low recycling rates in India; collection and segregation of waste dominated by informal sector, high level of uncontrolled dumping, voids in regulatory, legal and legislative frameworks for waste management.

Table 2.5: Recycling in India

2.8 Use of Analytic Hierarchy Process (AHP) as Decision Tool:

The Analytic Hierarchy Process (AHP) is an effective tool for analysing complex problems and arriving at a balanced decision. It helps to choose the best solution by assigning priorities and systematically weighing the various options. The AHP helps in capturing both the subjective and the objective characteristics of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus, reducing the bias and normalising the decision-making process (Saaty, 2008). The computations made by the AHP may appear to be guided by the decision-maker's experience. Therefore, a method of group decision is used whereby a small number of domain experts with slightly varying experience and skill sets are asked to opine on the same set of comparatives (Z Srdevic, 2011). AHP is a powerful decision making tool which has been used across many environments for comparing multiple options and arriving at best solution using weighed option from domain experts. Few research paper on the subject which were referred during this research are listed below in table 2.6: -

Sl No	Source	Author	Research Takeaways
1.	"Use of Analytic Network Process for Supply Chain Management"	Tomokatsu Nakagawa (Tomokatsu Nakagawa, 2004)	The paper explains the steps involved in use of Analytic Network Process (ANP) in evaluation strategic decisions for a Supply Chains. ANP formed the basis for development of AHP
2.	"A strategic service quality approach using AHP"	Clare Chua Chow (Clare Chua Chow, 2006)	The paper develops a technique to measure quality of service using AHP. The conceptual framework proposed in the can be used to evaluate the RSC for used oil.
3.	"Decision Making with AHP"	Thomas L Saaty (Saaty, 2008)	The paper highlights the use of analytic hierarchy process to improve the decision making capabilities in inconsistent environment
4	"An AHP-based weighted analysis of network knowledge Management platforms for elementary school students"	Chung Ping Lee (Chung-Ping Lee, 2011)	The paper uses AHP based study to analyse the impact of teaching using electronic media in Off-Campus mode. The learning mode of students is also evaluated using digital mode.

Sl No	Source	Author	Research Takeaways
5.	"Validating AHP for eliciting colorectal cancer screening preferences using online questionnaire"	Nick GK Mulder (Mulder, 2011)	The author implies that prediction of impact of different screening technologies using AHP is not very useful in case of health service in online mode of consultation.
6.	"AHP based group decision making in ranking loan application for purchasing irrigation equipment: a Case Study"	S Srdevic, B Blagojevic (Z. Srdevic, 2011)	The paper uses AHP to analyse a real life problem for purchase of farm equipment by various decision parameters
7.	"Sustainable benchmarking of supply chains: the case of the food industry"	Natalia Yakovleva (Natalia Yakovleva, 2011)	The paper uses AHP to evaluate the food chain industry. The performance indicator identified in the paper and the method of sensitivity analysis can be used to develop the RSC for used oil.
8.	"Application of Analytical Hierarchy Process (AHP) Technique to Evaluate and Selecting Suppliers in an Effective Supply Chain"	Shahroodi (Shahroodi, 2012)	The paper suggests method for identifying the best supplier from amongst a large group of service providers in order to design a sustainable supply chain. The learning from this paper were used for designing the RSC for used oil
9.	"Potential Hazard Map for Disaster Prevention Using GIS-Based Linear Combination Approach and Analytic Hierarchy Method"	Szu-Hsien Peng (Szu-Hsien Peng. Meng-Ju Shieh, 2012)	The paper uses AHP to measure and grade the effect of various factors that influence natural disasters. The comprehensive method of identifying experts across variety of domains can be used for identifying experts for RSC of used lubricants for aviation sector.
10.	"Supplier Selection Based On AHP Method"	Chengjing Jounio (Jounio, 2013)	The paper uses AHP to select the most suitable supplier.
11.	"Pressure analysis for green SCM implementation in Indian Industries using Analytic Hierarchy Process"	K Mathiyazhagan (K. Mathiyazhagana, 2014)	The paper focuses on the regulatory demands on Indian industries for adoption on green norms. Using AHP, the author evaluates the industries outlook on the subject.

Sl No	Source	Author	Research Takeaways
12.	"An AHP based approach - selection of Measuring Instrument for Engg Inst"	Dr. S.Saravanan , (Dr. S.Saravanan , 2014)	The paper uses AHP for finding the best solution by evaluating the opinion of teachers and students.

Table 2.6: Use of AHP tool

In today's business environment, it is important to arrive at the best solution for given problem at the shortest possible time, as delays may lead to financial losses. Analytic Hierarchy Process has proved to be a fast, inexpensive and reliable decision making tool for arriving at most practical solution. This scientifically designed analytical tool is also being used extensively by researchers to arrive at solutions in many management research problems. AHP tool is being used in this research for optimizing the reverse supply chain design used for collection and post use management of used aviation oil.

2.9 Technology Feasibility: Aviation Oil Reclamation: According to the available literature, lubrication oil in manufactured from different sources like synthetic base-oil or mineral (petroleum) or a combination of these. Each source has its own unique physio-chemical base property. To enhance these, additives in the form of special chemicals are added to improve specific characteristics like: - friction reducers, high pressure performance boosters and anti-wear compounds, to name but a few. Further, as per the review of papers, journals and books available in open domain and exclusive technical libraries of research institutes, the reclamation process involves removing all types of additives and contaminants from the used oil to obtain fresh base stock. The oil recovered after reclamation is as good as fresh oil received from a refinery. While a lot of technical and exploratory research has been carried out on ways to reclaim automobile oil, hardly any work has been done on aviation oil.

It is evident from the above, that while a lot of experimentation has been done on ways to improve the quality of base stock recovered (reclaimed) from waste oil, very limited work has been done to optimise the collection of waste oil by treating it as a re-usable product. This thesis is an effort to treat used aviation oil as a recyclable product and design a reverse supply chain model which aims at maximising collection and minimising unsafe/ improper disposal of waste aviation oil.

The in-depth study of academic research articles, technical publications and interaction with academicians and scientists it has also been established that there exists a technical similarity in the processes of reclamation of aviation oils and automotive oils. Therefore, it can be inferred that: -

- ✓ Aviation oils can be reclaimed by processing them as automobile oils.
- ✓ The quantity of base stock oil recovered from aviation oil could be much higher than from automotive oils, with the use of better technology.
- ✓ There is a need to develop an industry specific reverse supply chain to ensure that aviation oils can be reclaimed as a commodity.

2.10 Research Gap This literature survey and review of publications available in public domain, no specific insight has been found to suggest existing business strategy for a RSC for used aviation oil in India. The literature also does not present any scientifically investigated study towards optimising the reverse supply model for aviation oils towards comprehending its economic potential. This leads us to identifying the research gap in the literature and also the industry. This gap can be stated as: -

- ✓ Existing literatures does not provide an insight into the existing business strategies, for realizing financial benefits from used aviation oil

- ✓ No study report/ survey on efficacy of existing regulations, policies and laws on waste management in India w.r.t. aviation oil

- ✓ No reverse logistic supply chain model to optimise the collection of used aviation oils for reclamation purpose.

From above, the problem statement for this research work has been carved out and is stated as: -

<u>Study the existing practices for disposal of used aviation oils and develop a suggestive RSC model for reclamation of used aviation oils in India.</u>

The next chapter discusses in detail the evaluation of reverse supply chains for polluting products. The chapter also deliberates on various close loop models suggested by eminent researchers and methods to evaluate their performance. On analysis of these models, a framework for modelling the reverse supply chain for used aviation oil has been suggested in the subsequent chapters.

CHAPTER 3

REVERSE LOGISTICS APPROACH TO RECLAMATION

3.1 Introduction

Economics considerations resulting in the reduction in material and production cost of new products could have been amongst of the primary reasons for the propagation of the theory of reuse, recycle or reclaim. With the advent of time, both manufacturers and users realised that recycling of certain items was far more economical and safe than its disposal. This thought process necessitated the need for collecting reusable products. The efficient use of Reverse Supply Chains (RSC) for enhancing the collection of scrap and waste materials like metallic/ non-metallic scrap, discarded paper, packing material, soft drink bottles, etc., have been in vogue for long. Concurrently, environmental concerns have also stimulated inclusion of many more products in the list of ‘reusable' items. In the previous chapter, section 2.5, the ongoing research on the waste reduction efforts of various agencies were briefly discussed. These efforts further nurtured awareness for developing robust reverse logistic chains that streamline collection of used items and integrate it into their forward supply chains as cost reduction and green environment measures.

According to a research conducted by the European Commission, during the year 1994, only 27.7 million tonnes of used paper was recycled in Europe (European Commission, 1997). Thereafter, meaningful consumer awareness campaigns by green organisations led to a huge increase of over 70% in collections, by the year 2000. According to the data recently released by the European Paper Recycling Council (EPRC), in the year 2017, the paper recycling rate in EU had reached 72.3%. The council published that 59.6 million tons of paper was collected for recycling against a consumption of 82.5 million tons (paperforrecycling.eu, 2018). Europe has declared to targeted recovering 74% of the total paper consumption by 2020.

According to another research, recycling of glassware, packaging materials, transportation case, etc, have shown an upward trend in terms of collection (Central Bureau of Statistics, 1997). These efforts have been supported the concept of reuse and given rise to a new material flow system i.e. “from the user back to the producers”. Thereby, increasing greatly the recovery rate of recyclable waste. This was probably achieved due to improvement in consumers’ awareness about the damaging effect of waste disposal, stringent legislations and establishment of an effective ecosystem which supported the movement of the waste.

3.2 Reverse Supply Chains for Waste Products: An Overview

According to John McNabb, Germany first introduced a policy for the producers to take back certain re-useable items from consumers in the late 1990’s (McNabb, 2001). Thereafter, by the turn of the century, most “Fast Moving Consumer Goods (FMCG)” manufactures had introduced a ‘take-back policy’ to boost sales. They also provided financial incentives to consumers for returning/ replacing their old/ used products. While manufacturers gained from reduction in input cost towards purchase and processing of raw material, consumers gained from value addition and cash back for used items and disposal issues associated with waste products.

Such ideas which propagated re-use of household products and assigned value to waste, while adding new dimensions to movement of items in a supply chain. Thus compelling retailers and manufacturers to invest in RSCs. These chain originate from the point of sale of product and end-up at the recycler, reclaimer or second tier re-user. These new supply chain networks have supported in conserving natural resources, extending life of original product and reduce waste generation, while generating additional revenue for the user. RSCs have also created new jobs in logistics and reclamation industry.

Patricia OV from the University of Algarve, Portugal, had also suggested considering various factors analysing while designing reverse supply chain models These factors may include, knowledge of concurrent advancement in re-manufacturing technology, existing collection mechanisms and consumers' awareness about using environment friendly products (Patricia OV, 2009). From the study it could be considered that there exists sufficient scope for the inclusion of used oils in the list of re-usable product.

The first comprehensive research paper applying knowledge of a reverse logistics models on management of used lubricants was presented in 2010 at the 21st Production and Operations Management Society Conference, Canada, by Marcos D Gomes (Marcos DG, 2010). The life cycle flow of lubricants suggested by Marcos is shown in figure 3.1. The paper recommended the introduction of authorized oil gatherers and re-refiners as enablers for establishing the RSC of used oil. According to the Marcos, the efficiency of the chain is dependent on the waste handling capacity of the gatherers and re-refiners. The efficacy of the logistics chain, which connects waste generators to re-refiners, is very important in the overall

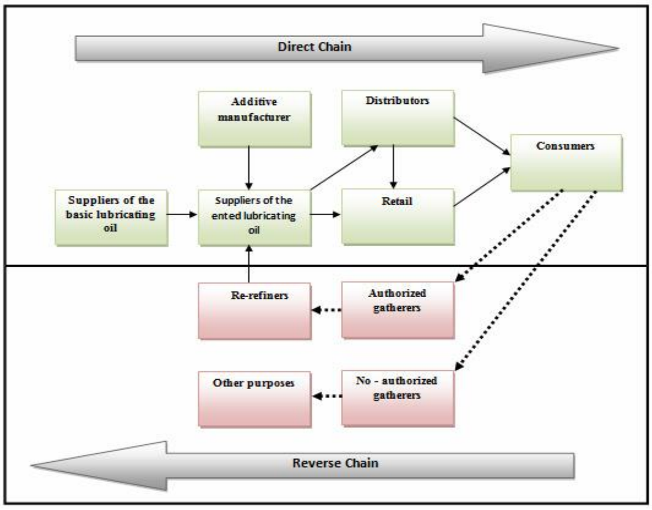

Figure 3.1: Direct & Reverse Chain for Lubes (Marcos DG, 2010)

management of quality, quantity and cost of handling of used oil. Therefore, it is necessary to design a RSC which optimises all applicable factors for ensuring cost effective reclamation. These factors are discussed latter in this chapter.

According to M Fleischmann, RSCs for scrap and waste materials have been in vogue in many industry sectors for long (M Fleischmann, 1997). Valuable realistic data on the economics of waste generation, its financial and environmental management, etc was made available only recently, through a study conducted by the British Department of Environment, Food and Rural Affairs, (DEFRA, 2011). According to the study, England's household waste generation grew from 17 MMT in 1985 to over 25.5 MMT by 2007, while commercial and industrial waste reduced from 70 MMT to 55 MMT during the same period. Studies like these have enabled reclamation to become a significantly researched field of logistics management. Concurrently, this has also prompted renewed interest in this branch of supply chain management, which deals with physical flow of substance opposed to the conventional flow, called as Reverse Supply Chains.

Referring to the deliberations in the previous chapter (literature survey), it is evident from Section 2.5, that while a lot of technical and exploratory research has been published on ways to reclaim automobile and industrial oil, limited scientific/ technical study material is available on theories for optimising the RSCs for used aviation oil. It is also observed from the market survey (primary data) and information collated by the Central Pollution Control Board (CPCB, 2018) that details on post-use management/ disposal of various types of lubrication oil has neither been adequately collated by the industry nor by the government organisations. Therefore, a need was felt holistically study the reasons for low collection of lubrication oils in India and design a reverse supply chain for its reclamation/ recycling/ reuse. This research discusses and suggests a theoretical model which optimises collection of lubrication oil in India. The thesis proposes to: -

- ✓ Estimate the quantities of waste/ used lubrication oil generated in India, especially from the aviation sector
- ✓ Establishing a RSC for used aviation oil
- ✓ Optimise the chain for cost and quantity
- ✓ Help generate ancillary revenue, reduce imports and decrease the carbon foot print of the aviation sector.

Recent developments in re-manufacturing technology and growing awareness amongst consumers regarding use of eco-friendly products, has helped redefine the understanding of RSC networks. Industrial research has enabled inclusion of more merchandises in the list of reclaimable products and measure their output. The next section outlines the various reverse logistics network models proposed by researchers over the last three decades.

3.3 Types of Reverse Logistics Networks

Reverse logistics as the word suggests, is the "reverse flow of material as against the forward logistics" (Beamon B M, 1999). Dowlatshahi defined reverse logistics as "a process through which a manufacturer is ready to accept a previously shipped product from the point of consumption for possible recycling/ re-manufacturing" (Dowlatshahi S, 2000). Thierry, Wassenhove, Van Nunen and Salomon (Thierry M, 1995) have indicated that automobile manufacturers such as by BMW and General Motors, etc and IT giants like as Hewlett Packard, HCL and TRW had tailored their reverse logistics network for customer support since the early 1990's. These organisations had designed and treated reverse logistics as another supply chain process which could provide them financial gains as well as valuable consumer support. The managements had ushered in this concept for recall of failed products where the item or sub-assemblies were required to be brought back from different customers site/ workplace, to the repair facility for refurbishing.

Similarly, Caruso et al described reverse logistic model as a “network for solid waste management system which includes its collection, transportation, incineration, composting, recycling and disposal” (M C. C., 1993). He termed the network as a “multi-objective location-allocation model” and suggested a heuristic plan for waste management. The procedure included identifying the location of waste disposal plants, recognizing the best technology for the product and optimising waste processing. Kroon and Vrijens also presented a reverse logistics system for return of reusable containers which was later developed as a case study for a logistics service organisation. The paper describes the movement of returnable shipping containers in Netherlands. (Leo Kroon, 1995). The research paper analysed the transportation, maintenance and storage of empty containers and thereafter, suggests a “plant location model”. The paper uses the idiom “Return Logistic System” to analyse the flow of used containers.

M Fleischmann, also suggests that Reverse Supply Chain or Reverse Logistics to be a group of logistics activities which commence from the point an item is no longer needed by the consumer to the point it is reclaimed to a form that is becomes usable for the industry (M Fleischmann, 1997). He recommended that the recycling process can be divided into three set of activities. The first set of activities may involve the physical movement of items from the consumer (end user) back to the recycler and is represented as the *Reverse Logistics Networks.* The next set of activity is the recycling/ reclamation of the returned products. This set of activities is called *Product Recovery Phase*. The last set includes activities relates to the cost build-up of the process and revenue generation. This set may include the cost of collection, transportation and reprocessing. All activities relating to this set put together are called *Inventory Analysis*. These three group of activities can be used to evaluate the entire process.

From the above illustrations it is evident that over the last three decades, the concept of Reverse Supply Chains has developed considerably and gradually matured as a separate branch of logistic management. Like forward supply chains, the RSCs are also characterised by factors like cost, time, consistency and optimised as a transportation problem. According to researchers, the most important factor that determines the design of RSC is the feasibility of product to be re-usable, recyclable or reclaimable. To sum up, it can be stated that a Reverse Logistic Network can be designed for any product provided that: -

(a) Technologies are availability to reclaim or recycle the used or waste product.

(b) The technology is environmentally safe and reduced the carbon footprint of the effluents

(c) The estimated cost of replacement or process cost of reclamation, including the cost of collection, segregation, transportation and disposal of waste, is less than the price of finished product.

Thus it can be stated that RSCs are defined as supply chains designed for recyclable and/ or re-usable products, and optimised according to cost of product, cost of reprocessing and time. The chain refers to the movement of products from the point of end-use or point of rejection to the point it moves out of the re-processing facility as a new product. It includes all the principals of logistic management like process planning and control, efficient storage and transportation and product Life Cycle Assessment (LCA). These factors are discussed in the subsequent sections.

3.4 Reclamation as an Objective of Reverse Supply Chain

Waste reduction and environmental ill-effects of industrial effluents are drawing adverse attention globally. Therefore, laws are being enacted to make manufacturer and consumers equally responsible to the environment by ensuring re-use of more and more products and sub-assemblies (MoEF&CG, GoI, 2016). Thereby ensuring extension of the life-cycle of product and material. The obligation to take-back a product after use with a view to reduce waste generation, is one such measure. Re-collection of used packaging material is one such example. In Germany, the Packing Ordinance 1991, mandates the use of recycled material in all new packing products. Similarly, the Electronic Scrap e-Waste (Management & Handling) Rules, in India, mandates recycling of all electronic and electrical goods including scrap from FMCG products (Dave, August 2016). Such regulations have compelled manufactures to initiate 'take-back' policies. These take-back policies have added a new dimension in the management and operationalisation of supply chains, where reclamation or recycling is the objective for setting up of reverse supply chain.

Traditionally, the customer/ consumer is the end of a typical supply chain. However, if take-back polices are encouraged, the current user of the old product, from whom the product is to be collected, becomes the point of origin of supply chain. The collection of 'end-of-life products' from existing consumer for the purpose of recycling/ re-use/ re-manufacture, presents an opportunity for extending the life of the item, conserve resources, prevent waste and generate additional revenues. Such chains which originate at the termination point of regular supply chains and end at the manufacturing/ reclamation facility are termed as Reverse Supply Chains for 'end-of-life products. With the advent of new reclamation technologies more and more products are being included in the list of recyclable items. These chain presents new business opportunities by creating jobs in logistics, warehousing, re-engineering and reclamation sectors.

These RSC are new order of supply chain which facilitate the flow of used products from the consumer back to the reprocessing plant. However, in practice, RSCs are more complicated then forward supply chains, since the return movements may include rejected/ failed item and materials. Therefore, these products may require sorting and dismantling before entering the repair, re-processing or production line. Concurrently, the chain may also have multiple exit point for products, one for each by-product generated during sorting and dismantling. The author explains that the design of the RSC model is dependent on the characteristics of the product. The distinguishing features of the product being its utility or usability on return.

Interestingly, eminent researcher, M Fleischmann has enumerated the different RSC models as per the features and characteristics of the used product (Fleischmann, 2001). The criteria on which the models are can be designed are listed below: -

(a) **Product Life Cycle Returns**: "Items returned under this category are linked to the sales process. The reasons for the returns from the Point Of Sale (POS), may include problems with items under warranty, damage during transport or products recalled due to manufacturing defects."

(b) **Re-Usable Components**: "This head includes return of items related to consumption, use or distribution of the main product like customised packing cases, pallets, etc. These items are returned to the original equipment manufacturer for re-use".

(c) **End-of-Use Returns**: "These are used items, components or sub-assemblies that have been returned after the customer's usage. These used items are normally traded in the open market as articles of trade for being remanufactured, like exchange schemes for TVs, fridges, old furniture and other consumer goods."

(d) **End-of-Life Returns**: "This classification includes those items that are returned or taken back from the customer/ market to avoid environmental or commercial damage." This category is governed by take-back laws, and the products' ability to be recycled cost effectively. Items like used car tyres, batteries, electronic circuit boards, etc fall under this category. Used aviation oils, which are drained from aircraft after completion of its service life, fall under this category of products.

Further, recycling data from few countries suggest that public opinion, and awareness of environmental issues impose strong pressure on companies to consider reusability while developing new products (Cascini, 2015). 'Green' image for products have become marketing strategy for increased sales. This has stimulated managements to explore at possibilities to takeback products for reclamation (Thierry, 1997). Concurrent with these developments, the manufacturing industry also started venturing for solutions to offset environment concerns. Most manufacturer in consultation with service industry devise plans for recycling industry waste and consumer returns. The next section discusses this product-based RSC.

3.5 Product Based Reverse Supply Chains

Most RSCs are optimised for maximizing recovery of usable products from discarded items. These chains optimise the process of replacing the failed product noticed at the customer's end or Point of Sale (POS) with a serviceable item, in the shortest possible time (Miying Yang, 2018). The failed product would then be required to be transported to the manufacturing unit or workshop for re-work as soon as possible. Concurrently, the item is also required to be replaced at the customer's end at the earliest. From the point of view of inventory management, each failed or rejected delivery is characterized by two features. Firstly, every new rejection (at the point of sale) generates a demand for new item, i.e. the item requires to be replaced with a new and serviceable item. This situation leads to a reduction in the inventory of new items held by the seller without an actual sale. Secondly, the rejected item, though not consumable or saleable remains in the inventory until a closed loop supply chain generates a process for its return for its repair, re-processing or re-cycling at manufacturing or offset facility.

This system, where the rejected product is recoverable and can be reused after re-processing as a new product, leads to dual identity inventory for unsold products. This inventory management system was modelled by Cohen (Cohen MA, 1980). He professed that a fixed share of the merchandises sold during a given period will be returned to store after a fixed lead time. His model was similar to the stochastic inventory model for rejected items situation (Yossi Aviv, 1997) with proportional costs offset. From Cohen's model an estimate of returnable inventory can be drawn. Concluding that most product, would have a surplus non-saleable inventory attached to it. Therefore, the objective of SC dealing with such products is to optimise the trade-off between holding costs and storage costs. Cohen suggested a max order formula to optimise such inventories (Cohen MA, 1980).

While evaluating further the concept of Product based Reverse Supply Chains, it was evident that no single model could correctly establish a numerical relationship between rejected inventories and quantum of re-engineering activity required on the item. This fact justified that the characteristic of failed product plays an important factor in the designing of the RSC network. A review of the literature on the subject interestingly, brought out a number of studies that indicate of a mutually inclusive relationship between 'failed-product' based inventory control and its re-production capability. Therefore, the next important instrument in deciding the capability of the network was- 'How to estimate the number of failed-products for which the reverse chain is to be designed?' From the perspective of operations management, this is an important input required for designing the size of the transportation packet for the network which handles re-usable and recyclable products. The number of failed units would also decide the size of the reclamation industry.

Considering these aspects, JL Mishra suggested for modelling the network on the concepts of Circular Economy (Joyti L Mishra, 2017). Under this concept, each product is assigned a service life. On completion of this period of utility all in-use products are returned by the customer to the manufacturer or reclaimer. Circular Economy models are designed on the assumption that a number of sub-products, materials and natural resource can be regenerated from any product which is completed its service life. Circular economy believes in generating wealth from waste. From these research papers, it is understood that the aviation oils can also be considered as a product which has a designated service life and thereafter it can be reclaimed. Therefore, the reverse supply chains for this can be tailored on the concepts of Closed Loop Supply Chain Management (CLSCM) and Life Cycle Assessment (LCA). The merits of these network models with respect to polluting products like reclamation of used aviation oil is discussed below: -

3.5.1 Closed Loop Supply Chain Management

The rate of reclamation of polluting products can be improved by using the concepts of Closed Loop Supply Chain Management (CLSCM) in the recovering the products. CLSCM considers the economic and ecological factors, along with operational and financial factors as objectives for optimising the supply chain. CLSCM also meets the requirements of the environmental legislations, by encompassing concepts of Waste Management and Product Life Cycle Assessment for Green Operations (Reverse Logistics). Application of CLSCM leads: -

- ✓ Saving in cost of operation.
- ✓ Optimum resource utilisation
- ✓ Control over pollution
- ✓ Decline in waste generation

3.5.2 Life Cycle Assessment for Reverse Supply Chains

Another philosophy for modelling a RSC is use of Life Cycle Assessment criteria for optimising the chain. The goal of LCA is to compare the full range of environmental effects assignable to a product by quantifying all inputs and outputs of the material and assessing how these affect the environment. This information is used to improve processes, support policy and provide a sound basis for extending the scope of reuse or reducing environmental effect of a product (Cascini, 2015). Cradle-to-grave is the full LCA tool which evaluates the product from the resource extraction ('cradle') phase to the disposal phase (‘grave'). LCA of minerals, metals and engineered material plays a significant role in saving energy, conserving resources and generating ancillary revenue for organisations. The LCA also gives the true environmental trade-off of a product for its in-use valuation vis-à-vis, post use management. Analysis of this kind have help increase the life of many products like plastics, aluminium cans, beer bottles, newsprint, packing material, etc. The takeaways of the study include saving energy in producing a new product and reduction in the demand for extruding fresh metal from minerals and ores. Information on LCA of lubrication oil can be an important criterion for driving government policies in enforcing reclamation (Micheal Collins, 2017). Further, the comparison between total energy cost in producing fresh stocks of oil as against energy consumed for reclamation justify efforts for increasing collection. Reclamation of used oil takes only about one –third the energy of refining crude oil to lubricant quality (US Department of Energy, 2006).

3.6 Characterisation of Products for Reverse Supply Chain

Traditionally, RSC dealt with products at the end of their lifecycle and aimed at recovery of product value at least processing cost. Therefore, most RSC were designed to carry out five main processes: product acquisition, reverse logistics, inspection and disposition, remanufacturing or refurbishing and sale of recovered products. Eminent scholars have suggested various different designs for modelling, planning and optimising RSCs. Each design is generally tailored to suit a particular recyclable product. However, before selecting the best framework and designing the finest regression model for any recyclable product, it is necessary to evaluate its lifecycle. For this, it is also necessary to characterise the items (including sub-assemblies) according to its post-dismantling utility. Therefore, from the point of view of reclamation, each product has to be placed under one of the following criteria. A product or it's sub-assembly may co-exist in more than one group. The bifurcation of the groups according to the characteristics of the product is discussed as follows: -

(a) **Criteria 'A': End-of-Life Returns**: This group encompasses products which after having completed their designed service life, have to be recovered from the market to prevent them from causing environmental and/ or commercial losses. This group includes newspapers, car batteries, electronic appliances like computer motherboards, etc. The products under this group cannot be simply re-engineered or repaired to restore their usability. Each product may require to undergo multiple technical processes to become usable. Generally, the products under the list yield raw material for new products. A common reserve supply chain that runs from the end user to the sorters represents this model. The chain handles a large variety of products. According to Henrique Luiz Correa, designing an effective reverse supply chain model for reclaiming a product which has reached 'end of use' life has many challenges (Henrique Luiz Correa, 2013). According to the author, these challenges include reclamation technology, taxation policies, regulatory issues, sorting cost, plant location, etc. Therefore, it may be difficult to correctly estimate the cost of reclamation technology without factoring each of the subsequent variables. He suggested that such model should therefore, be regressed product-wise and optimised based on volume. Used newspapers, lead-acid batteries, tyres and plastic containers are a few products that could be included in this group for the purpose of estimating cost of reclamation as variables are fairly well defined.

(b) **Criteria 'B': End-of-Use Returns**: Products that have completed their intended use are included in this list. Products under this category do not lose their functional utility or characteristics post use, and generally do not undergo any drastic change or degradation during use. The group include items like packing cases, special transportation containers, beer bottles, etc. The items can be reused with cleaning and minor refurbishing or repair. No extensive re-engineering process is required before re-using the product. The RSC for such items can be modelled analogous to the forward supply chain as the number of items (in reverse chain) and location for collections are predetermined (Marisa P. de Brito, 2002).

(c) **Criteria 'C': Product Based Reverse Supply Chains**: This list is based on the recyclability of the product and the material from which the product is made. For example, the RSC for used plastic containers is based on material used for its production and includes all types of plastic container. Industrial use plastic containers and household containers require the same process for reclamation. The RSC leading to the reclamation process is based on the material of the product rather than its use. The chain has many determinants for correctly estimating waste generation as the product can be obtained from multiple sources, thereby affecting the quantity, quality and transportation effort for the collection of raw material. The processing cost and rate of reclamation can also be improved if correct estimates of collection are made and matched with production (recycling) capacities (Curtis Greve, 2002).

(d) **Criteria 'D': Process Based Reverse Supply Chain**: Some recyclable products are uniquely process dependent. For example, automobile parts, computer mother boards, etc. Each product needs to be regressed through a unique process. The product has to be dismantled, sub-assemblies sorted and then reclaimed using different technical process. The production planning for reclamation is based on the size and type of the item to be recycled. Therefore, for each reclaimable product, the MRP model and BOM algorithm discussed earlier need to be optimised, depending on the process to minimise recycling time and cost. This model has been used most widely by the logistic industry and has potential to generate maximum gains if optimised correctly (Gobbi, 2008).

3.7 Process-Based Reverse Supply Chain

Type and size of the inventory, that the chain is likely to handle is another criterion that is used to decide the best working model for RSCs. As production planning for reclamation is governed by type and size of the inventory which is likely to be processed. For example, in case of direct reusable items like packing boxes/ cases, beer bottles, transportation packages and pallets, where returned products can be reused in 'as is' condition (possibly after cleaning or minor repair), no additional production process is needed. In such cases, inventory control rather than production planning takes priority while optimising the RSC. The production process for returned products may only require refurbishing. M Fleischmann, opined that the difficulty in organising such RSCs is in creating a network for the collection of reusable product rather than in planning and controlling the re-engineering activities. As traditionally, the activities of collection of used/ recyclable product was beyond the scope of planning processes.

From literature review, it is understood that inventory management for RSC could become a complex task if some technical activities like disassembling, sorting, etc are required before the start of the re-engineering process (Jayaraman, 2006). In most cases, the extend of refurbishment activities needed to convert a rejected/ returned product to a 'recycled as new' state largely depends on the state of the received product. This number of engineering activities may vary from item to item and product to product.

In general, a pre-receipt inspection of the article is required to estimate the number disassembly operations required for executing the re-manufacturing task. Some synchronization of job may also be required at this stage, as a number of sub-assemblies may be releases simultaneously during the disassembly of the returned product. Concurrently, repetitive re-engineering may be required on some parts while no work may be required on others. Each items will require different scheme for refurbishing therefore, multiple sorting and inspection may also be required. This shows that production planning in reclamation process or re-engineering environment is much more complex. In cases where the RSC is dependent on the number and types of (reclamation) processes, Material Requirement Planning (MRP) and Bill of Materials (BoM) are two effective optimisation tools (M Fleischmann, 1997) for such RSC. The tools are explained below: -

3.7.1 Material Requirement Planning

MRP is a concept of planning, where the production activities are scheduled according to the requirements for the varying demand of finished product from the same production line. The use of MRP model in the production line where one of the items is a reclaimed item is a well-researched topic. Several authors have analysed the industry practices under this concept, in particular, the criteria for choosing between using a reclaimed component from the disassembly line or a fresh component from the store (Fernanda MP Raupp, 2015). Thus, MRP would be one of the decision criteria during the optimisation process. The concept would be used while formulating the questionnaire for AHP this is discussed in the next chapter.

3.7.2 Bill of Materials

Another, conceptual tool for designing and optimising RSC, is the concept of 'reverse' Bill of Materials (BOM). In this concept, the characteristics of every returned product, which is fit for reclamation, is documented, and time required for dismantling the sub-assemblies is estimated. Thereafter, a schedule and sequence for disassembly operations is made out, taking into account the variations that may occur between similar items in the same product line. The component with the largest time and space requirements will determine the size and layout of disassembly/ re-engineering line. The objective is to design the layout for most cost-efficient production line with regards to time and cost. For each type of item received for reclamation/ reengineering, a separate BOM is prepared. The BOM specifies the expected number of reusable components that are likely to be generated and accordingly schedules the production activities. On similar line, a variety of lubricants are used in the aviation industry, each of these may require different processing technology and/ or chemical treatment for reclamation. Therefore, segregation, MRP and BOM would be important considerations in designing the scope of the network.

3.8 Characterisation of Process for Reverse Supply Chain

The concepts of MRP and BoM are used to correctly estimate the reprocessing efforts, reclamation cost and market value of end product which designing the reverse supply for used lubricant oil in the subsequent chapter. The concepts also help in formulation of the Criteria (Nodes) and Variables (Performance Indicators) for the value chain design suggested in Chapter 5.

Therefore, for designing a RSC for any reclaimable product it is necessary to consider all the factors that are likely to influence the efficacy of the chain. From literature review Chapter 2, section 2.5, it is inferred that the efficacy of any forward supply chain is affected by time and cost (Arvind Jayant, 2012). Similarly, the RSC for recyclable items is also affected by time, cost and their derivatives like volume and technology (Larsen, 2014). On analysing the various concepts of RSC and their characteristics, two issues emerge, firstly, the availability of the Environmentally safe and cost-effective technology for re-processing/ reclaiming a product is central to designing the RSC. Secondly, the knowledge of volume, cost and time are crucial for optimizing the value chain. Therefore, complete knowledge of the product, its post-use disposal/

management ecosystem and options for its economic reclamation process available with the industry is essential for designing a suitable RSC. These factors are essential elements which need to be considered while designing any RSC model, this is discussed in the subsequent paragraphs.

3.9 Designing Reverse Supply Chain for the Indian Market

From literature review, it was evident that items like electronic gadgets and appliances, batteries, glass and paper were some of the items which were traditionally being recycled globally. However, recently items like oil/ tyres/ tubes/ rubberised items from automobile sector, aluminium cans, synthetic dress material, and edible oil have been added to the list of recyclable products due to advancement in technology. Recycling not only saves energy, reduces pressure on production/ extraction of new material but also reduces the carbon footprint and landfills (Robert E. Wright, 2011). While, across the world, availability of cost-effective technologies for recycling have enabled inclusion of more and more products into the list of recyclables, data available with CPCB reveal a poor rate of reclamation of these products for India (Central Pollution Control Board, Oct 2018). In the opinion of the researcher, there could be many reasons for this low collection, a few of them are listed below: -

- ✓ Lack of awareness/ motivation for consumers and local authorities.
- ✓ Low rate return to the consumer on selling these products.
- ✓ Added effort/ cost for organised disposal.
- ✓ Inefficient logistics with respect to sorting and transportation.
- ✓ Economy of effort due to low volumes (collection).
- ✓ Lack of geographical/ regional mapping of the volume and logistics of ecological waste disposal.

Therefore, a need is felt to acknowledge these issues and institute measures to improve the rate of collection and reclamation in India. A systematic overview of factors influencing the reclamation margins of each item is required to be researched. The determinants for a reverse logistic chain according to the type of product/ brand, quantities generated and geographical location of reclamation facilities, etc can be explored in detail and thereafter, a RSC for each product can be drawn-up and optimised.

However, before discussing the design of RSC for hazardous waste like lubrication oil in India, a preview of the enabling regulatory mechanism for used oil is presented. The policy framework covers a vast variety of waste materials which include used oil.

3.10 Preview of Regulations on Reclaiming Used Oil in India

In September 2008, the Ministry of Environment and Forests first issued a Gazette notification publishing the "Rules for Management, handling and Transboundary (Import/ Export) movement of Hazardous wastes". These hazardous wastes rules included used oil/ waste oil generated from the automobile sector and other industries (including the aviation sector). However, the definition of used oil was re-worded in the revised Gazette notification on "Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016", issued on 04 April 2016 (MoEFCC, 2016). According to these, any oil that fulfils the following conditions is described as used oil: -

- ✓ Any type of mineral or synthetic blended oil which has been previously used as engine oil, hydraulic oil, brake oil or gear oil in automobile sector. Spent/ used oils like transformer oil, compressor/ turbine oil, industrial gear oil tank bottom sludges, heat transfer oil, etc are also considered as used oils.

- ✓ According to “Part A of Schedule V”, (MoEF&CG, GoI, 2016) any oil that meets the following specification is suitable for reprocessing: -

Sl No	Parameter	Maximum Permissible Limits
1.	Poly Chlorinated Biphenyls (PCBs)	< 2 ppm
2.	Lead	100 ppm
3.	Arsenic	5 ppm
4.	Cadmium + Chromium + Nickel	500 ppm
5.	Polyaromatic hydrocarbons (PAH)	6%

Table 3.1: Specification of Used oil suitable for recycling. Source: MoEFCC

Concurrently, the 2008 rules for management, handling and transboundary (Import/ Export) movement of Hazardous wastes, had also listed the technologies that were considered to be environmentally safe for refining/ recycling/ reclaiming used oil. Between 2008-2013, the Ministry, through the Central Pollution Control Board, issued licences to a number of companies to recycle used/ waste oil. According to data compiled in year 2012 by an official from CPCB, only 19 states in India had registered (with state pollution boards) oil recycling facilities (PK Selvi, 2013). The total spent oil recycling capacity in the county, during that period was about 1.39 MMT, spread across 124 district from 257 industries/ facilities for reclaiming used/ waste oil. This establishes that there was a growing concern amongst regulators in India, to map the oil recycling facilities across the country. The approach may have been to incentivise, regulate and organise the sector so that lubricants are not dispensed off by the users as a hazardous and inexpensive waste and it can be recycled, re-processed or reclaimed using the best technology.

In the year 2015, the responsibility to issue/ renew licences to reclaimer for processing used/ waste oil was transferred to the respective state pollution control boards. According to the amendments inserted in the hazardous waste management rules in 2016, the state pollution control boards (SPCB)were also made responsible for the compilation of annual data on the quantities of oil reprocessed in the state (MoEF&CG, GoI, 2016). According to the ministry's notification, these efforts were aimed at curbing the improper disposal of hazardous waste and encouraging efforts for reclamation of lubricants. However, according to a researcher at the Central Pollution Control Board, Ministry of Environment and Forest, Govt of India, the major constraint faced in recycling waste / used oil was the cost of the collection, storage and its subsequent transportation to the recycling unit (PK Selvi, 2013).

3.11 Reverse Supply Chain for Aviation Oil

From the comprehensive research paper on post use management of lubricants presented by Marcos in 2010, it could be inferred that the collector and reclaimer were central to the RSC modelling (Marcos DG, 2010). The national hazardous waste rule 2016 (MoEF&CG, GoI, 2016) also acknowledges the existence of a similar model for the handling of used and waste lubrication oil. Based on inputs from literature review the RSC model suggest by the author in year 2010 can be adopted to represent the life cycle flow of lubricating oils in India. The figure 3.2 represents the flow of lubrication oil from the point it is manufactured at the refinery to it being used in various manufacturing and service industry, eg automobile, railways, power distribution (transformers) sector. Thereafter, it is discharged as used oil, which is collected by various aggregators and segregated

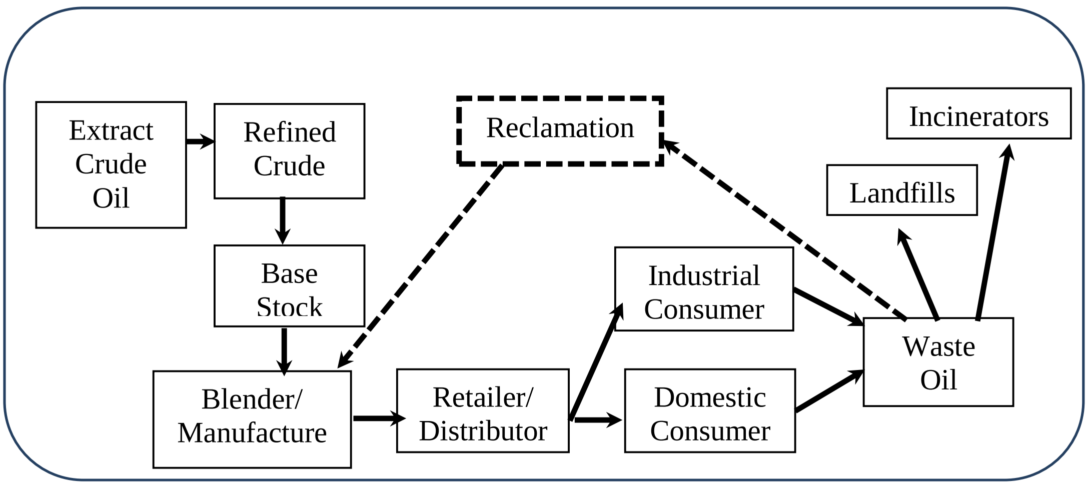

Figure 3.2: Forward and RSC of Lubricants

as hazardous and non-hazardous waste. While the hazardous product land up in incinerators or landfills, the non-hazardous reclaimable product is recycled as fresh oil for use by the industry. The flow diagram and process flow chart has been further exemplified to indicate the various transient stages in the life cycle of lubrication oils (British Columbia Used Oil Management Association: Annual Report , 2013). The design of the hypothetical RSC for used oil has been adopted from government data and secondary sources (Central Pollution Control Board, Oct 2018).

According to test reports produced by the Council of Scientific and Industrial Research - Indian Institute of Petroleum (CSIR-IIP) lab during year 2017, all types of lubricating oil like engine oil and hydraulic oils drained from aircraft can be classified as used oil (refer table 3.1) and reclaimed as any other lubrication oil. This thesis endeavours to study the post use management of used aviation oil in India for the purpose of reclamation as used oil. It is based on the LCA model for lubrication oils suggested above. This RSC model, for used/ waste oil, is adapted from inputs from industry experts to suggest the design framework for aviation lubrication oil. Thereafter, the model is evaluated and optimised for quantity, quality and revenue generation. The Analytical Hierarchy Process (AHP) tool is used for this purpose.

From literature review and contributions explained at para 3.7 above, the unique RSC model for aviation oils can be based on Criteria B - ‘End of Use’- concept. Concurrently, aviation oil can also provide better remuneration if a dedicated technology for recycling these oils is used as discussed in para 3.6 above. Therefore, the closed loop for aviation oil could also consider the criteria listed in ‘Process’ as discussed at para 3.7 (d) Criteria D. Accordingly, complete closed loop supply chain should also be optimised on all evaluative parameters discussed earlier. Summarising these, it can be stated that a dedicated technical process supported by a steadfast reserve supply line could increase the LCA of the aviation oil, reduce the carbon footprint and also generate ancillary revenue for the aviation sector.

The flowchart at figure 3.3, identifying the flow of lubricants from source till user. The flowchart has been prepared with inputs from various research papers and inputs received during market survey. The proposed movement of used oil is also superimposed on the flowchart in dotted lines. The diagram also shows the various activity nodes in the life cycle of oil. The model is based on 'Product Based RSC', where the product has reached the 'End-of-Use' stage. The bold arrows depict the existing flow whereas the dotted arrows show the proposed flow: -

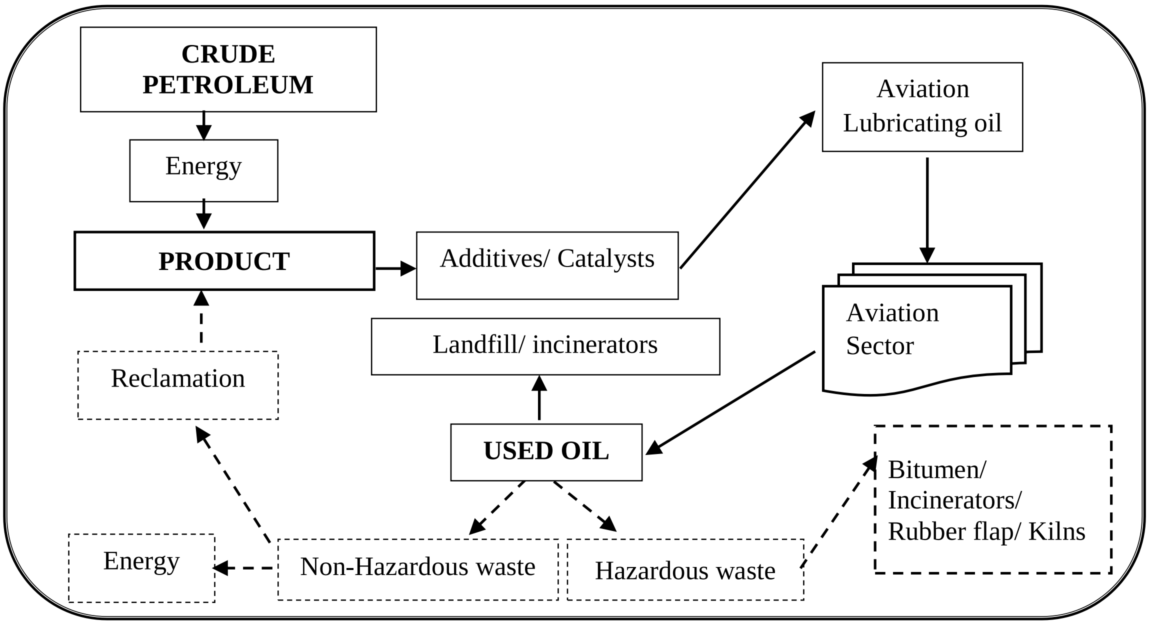

Figure 3.3: Life Cycle Flowchart for Lubricants

As in case of most mineral based lubrication oil, aviation lubricants are also produced from base stock that is obtained from crude petroleum distilled in refineries (Avi-Oil India (P) Ltd, 2015). The base stock is then blended with additives by the lubricating oil manufacturers and supplied to aviation companies. Each product is developed for a specific application. The distinctive characteristics of each brand of oil are obtained due to the unique mix of additives added to the same base stock. The life cycle of aviation lubricants in India can be traced only up-to this point in open source documents. Post use management of used oil is not documented nor disclosed by the industry. The data generated by the state pollution control boards have no mention of these figures (Central Pollution Control Board, Oct 2018). However, according to the international practices all types of used oil are to be collected and send for reclamation (Chari KR, 2013). This thesis is the based on the philosophy that aviation lubricants can also be reclaimed as automobile oils to produce base stock and can be reused to prepare fresh quantities of lubricants (A Shrivastava, 2015).

3.12 Conclusion

In India, independent private collectors collect used oil from automotive service centres, industries, aircraft MROs, etc. These individuals usually collect about 200-2,000ltrs of used oil daily and further sell it to the bigger contractors. Some level of cleaning and segregation of oil takes place at this level. Heavy sediment oil waste is sold as ‘fuel’ to brick kilns and as ‘lubricant’ to small scale industrial fabricators. The bigger contractors fall under the category of organised sector. They are in direct contact with the oil-recycler. Most oil recyclers in India re-filter the used oil and sell it as heavy industry lubrication oil. Some recyclers also reprocess or reclaim the waste oil to produce fresh base stock (Primary Data refer chapter 4).

The study of the industry practices in India also brings out that there is an urgent need to comprehensively review the management of lubricant oil by: -

- ✓ Increasing awareness and participation of aviation technicians.
- ✓ Enforcing regulations.
- ✓ Developing a RSC for transporting used oils.

A valuable outline on managing/ handling used oil for small businesses like fleet maintenance facilities, MROs, etc is given in the US Environmental Protection

Agency’s (EPA’s) code of Federal Regulations, part 279 (Resource Conservation and Recovery Act (RCRA) Regulation, 2012). The agency further strongly endorses the importance of segregating oil at the source as well as at drain-off point so as to ensure safe reclamation. It advises that used oil should not be mixed with any other waste whereby it becomes a hazardous waste. Handling/ re-refining/disposal of such oil requires a lengthy and costly process. Therefore, it should be ensured that used oil is segregated type-wise and batch-wise the moment it is drained after use.

On 12 December, 2017, the US congress during its 115th session adapted a bill that requires the Secretary of Energy to review and update a report on the energy and environmental benefits of the re-refining of used lubricating oil(US Librart of Congress, 2017). The bill directs the Department of Energy to update its report on the energy and environmental benefits of re-refining used lubricating oil and submit to the US Congress a strategic plan to increase the beneficial reuse of lubricating oil. The long-term plan shall address measures to: -

- ✓ Increase the responsible collection of used oil.
- ✓ Disseminate public information concerning sustainable reuse options for used oil.
- ✓ Promote sustainable reuse of used oil by federal agencies, recipients of federal grant funds, entities contracting with the federal government, and the general public.

The regulation of waste management in Europe and North America has fostered the creation of processes and activities that have ensured the establishment of the Reverse Logistics System (RLS) with strong fundamentals. The formulation of concepts, tools and regulation process has ensured better life cycle management of waste oil with widespread gains. The reverse logistics chain has also ensured development of specific knowledge about oil management, transportation, disposal and value adding skills that have improved the economic viability of the whole process.

The maintenance activities are fairly well organised, in aviation sector and organisations like the Directorate General of Civil Aviation, GoI (DGCA), govern adherence to regulations. Therefore, waste management rules for used oil can be easily implemented. The literacy level and general awareness of aviation technicians is much more than that in other maintenance set-ups. Therefore, the issues brought out above can be addressed comfortably if the higher-level managers are taken onboard this programme. The only issue that needs attention is the setting up of a robust RSC to ensure proper collection, and safe transportation of used oil and its effective integration with the reclamation process. The RSC for aviation oils requires knowledge of the collaborative re-processing systems, legal frameworks, and environmentally friendly technologies. Thus, the chain will involve much more than merely the transportation of waste from the MRO to the reclamation plant. Finally, the reclamation will use technology to allow the reinsertion of the reclaimed oil into the refining and blending stage.

In order to extend the life of aviation oil and reduce the cost of import of fresh base stock by the nation, it is necessary to design and optimise a reverse supply chin model. Used oil management in India is an important topic that has not received sufficient attention. Though recycling and reclamation has been permitted by the Government, it has not received the impetus that it deserves. The recycling sector is still informally organised and insufficiently supported by common laws and regulations. Reclaiming used oil can conserve oil resource, ease the nation's energy crisis, and provide a source of ancillary income to the industry. The process can also reduce the carbon footprint of the industry and help produce a greener environment. This thesis is an effort to map the various factors that influence the collection of waste oil for reclamation. It has evaluated various supply chain models and then suggests a RSC design for used aviation oils. The study is based on inputs from industry experts and academicians of eminence in the field of supply chain. This research also recommends regulatory and policy measures to improve the collection of used aviation oil which can not only generate ancillary revenue for the industry but also reduce the country’s dependence on imports.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

Post use management of non-consumables has over the last few decades developed into a subject of extensive research. This change has been driven by increasing cost of raw materials and concerns for reducing environmental damage caused by waste. Technologies for reclaiming, recycling and reusing waste has also matured over the years and have been very effective in reducing the net affluent outflow. These changes in the outlook of manufactures and awareness amongst consumers have given rise to an emerging field of logistic management called ‘Reverse Logistics’. The concepts of this field of operations management were discussed in the previous chapter.

Owing to the concerns for environment, regulatory changes were brought about by governments and strictly implemented by environmentalist. Concurrently, the industry also realised the advantages and coined the slogan “wealth out of waste”. However, the real problem lay in collecting, segregating and transporting the waste from the place of origin to the reclaimer. In order to mitigate these difficulties, various strategies were suggested by researchers and implemented by industries to find an optimised solution. Finally, it was agreed “No one-size fits all”. Meaning it was difficult to suggest a single model for Reverse Supply Chain (RSC) that could represent an economic solution for all kinds of reusable/ recyclable/ reclaimable products. A detailed comparison of various network models of existing business strategies was also presented in the previous chapter.

4.2 Research Gap and Problem Statement

Theoretically, used aviation oil, like any other lubricating oil, contains large proportion of reusable oil known as base stock. Similar to automobile, transformer and other industrial oils, aviation oil also have pronounced economic potential for reclamation. Therefore, from management perspective, considerable economic and environmental advantages can be comprehended by optimising the RSC for used aviation oils that leads to reclamation. The review of research work and case studies available in open domain offer limited discourse on the methods for exploiting the potential of used lubricating oil in India. Further, none of them offer any specific insight on the commercial value or the life cycle assessment of aviation lubricants particularly its potentials if reclaimed. This research endeavours to study the post-use management of used aviation oil and develop a sustainable reverse logistics chain model for its reuse. The aim is to recommend measures to maximise collection, ensure environmentally safe segregation, proficient transportation and optimise reprocessing for appropriate financial/ environmental gains.

From the literature review, it was evident that while many research papers have been published on RSC, most have suggested different methods to develop or improve efficacy of the chains tailored for specific kind of product. Few scholars have also discussed new techniques for optimising existing chains while analysing and comparing different RSC models. However, no specific model could be found to suggest measures for designing and optimising RSC network model for used aviation oil in India. With a clear objective to enhance its collection, reduce operational cost and minimise the sectorial carbon footprint. From this literature gap, the problem statement for this research was carved out, which can be stated as follows: -

Study the existing practices for disposal of waste aviation oil and conceptualise a reverse supply chain model for reclamation of aviation oils in India.

This research presents a customised model of Reverse Supply Chain (RSC) for used aviation oil. Using various inputs, the proposed reverse logistic network advocates to achieve the twin advantage of saving the environment and generating ancillary revenue for the Indian aviation industry. The research also tries to bridge the gaps which were identified during the literature review, which were: -

- ✓ Limited insight into existing business strategies, like the use of a specialised RSC for realising environmental and financial benefits for reclaiming waste aviation oil.
- ✓ Inadequate literature on RSC models/ designs for reclaiming used oils in India.

4.3 Research Objective

The success of any recycling process depends on two important factors which are, availability of sufficient quantity of recyclable material and technology for recycling. Therefore, the aim of this thesis is to study the existing procedure and practices for the disposal of used aviation oil in India, with a view to estimate disposable quantities. Thereafter, develop a suggestive reverse supply model for reclamation of aviation oils in India.

The research objectives of the research can be summarised as below: -

I. To study the existing practices for disposal of aviation oils, in terms of cost recovery and compliance with regulatory mechanism. Also, estimate the quantities of waste oil generated by aircraft.

II. To develop a reverse supply chain for collecting and transporting used aviation oil to reclamation plant. Thereafter, validate the inter-relationship between various factors that influence the reverse supply chain of used aviation oils.

III. To develop a transportation plan of used aviation oil in India.

4.4 Used Aviation Lubricant: Material Flowchart

Most of the logistics chains referred earlier in chapter 3 have discussed various RSC models for different kinds of polluting products. Many of these network models, especially those dealing with re-usable products, are founded on the concepts of Life Cycle Assessment (LCA), which targets at reducing the environment impact of the product. As a first step in designing the model for the logistics chain for used aviation oil, various theories for RSCs discussed in previous chapter were weighed for their suitability to be adopted for modelling the movement of used oil as a re-usable/ reclaimable product. These supply chains were further evaluated for their appropriateness in replicating the lifecycle ecosystem of used aviation oil, so that they can be used as reference framework model.

In section 3.10 of Chapter 3 on Reverse Logistics, it was discussed that used aviation oil can be considered as a polluting product which has completed its "End of Use" lifecycle. Further, it was also discussed that oil reclamation is "Process" driven, which mean's different type of oil would require different environmentally sound process for reclamation. Analysing these inputs a theoretical model for the forward and reverse supply chain was proposed (refers figure 3.2). The model depicts the forward and reverse flow of aviation oil. The suggestive network for the material flow, is reproduced below as figure 4.1.

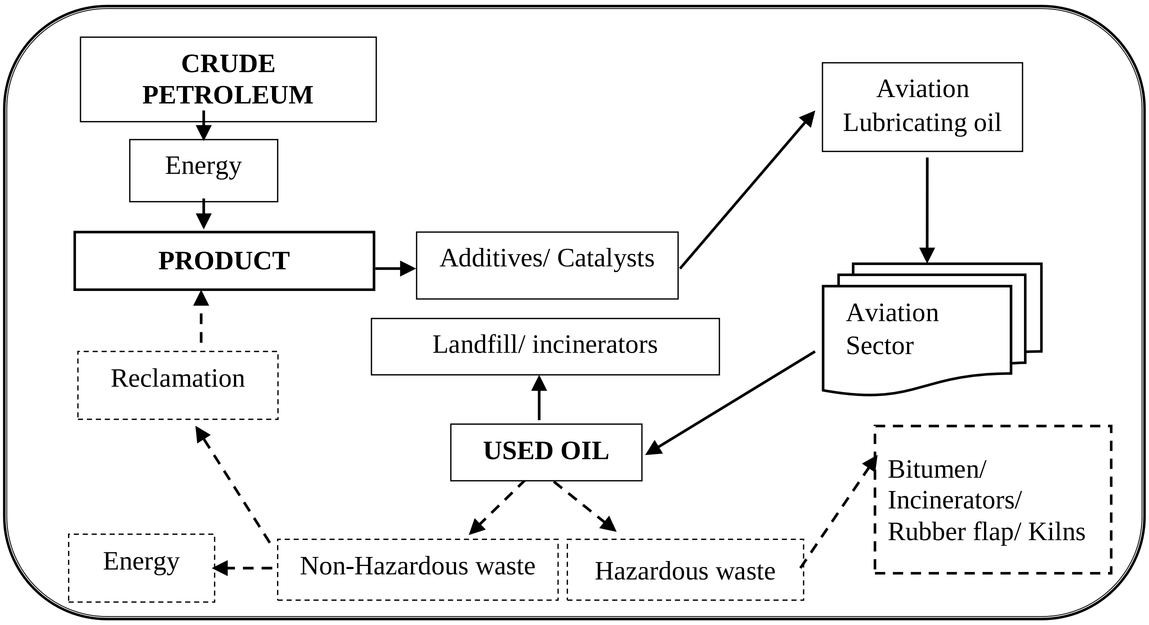

Figure 4.1: Material Flowchart LCA Perspective

With the help of this model the probable location of each 'node' was identified and its function and contribution shortlisted. On the bases of the functional role of each node, their 'performance indicators' (PI) were recognised. These PI are interdependent and distinctly influence each other in determining the overall performance efficiency of the chain. The performance of the theoretical network was measured by weighing the efficacy of each connected node against stated performance indicator The results were used to improve the network. Dr Andreas Seiler in his thesis titled 'Measuring Performance in Supply Chain Networks' provides important guidelines on methods to identify 'nodes' and 'performance indicators' that uniquely describe the arrangements of activities within the chain. The relationship between 'nodes' and 'performance indicator' should be clearly stated to meet the end-state requirements of the network, which is called as its 'Objective'. The author suggests methods to evaluate the performance of the supply chain (Andreas, 2016). The author further recommends that each criterion (Node) of the reference mode should be analysed along-with its matching set of variable (Performance Indicator) and decision parameter. Thereafter, iterative evaluation should be carried out, using variable quantities and parameters in accordance with the local procedures and regulations. Each such iterative cycle will improve the performance of the chain (network).

Accordingly, inputs on network architecture as suggested by Marcos (Marcos DG, 2010) (discussed at Section 3.2, Chapter 3) and Andreas Seiler (Andreas, 2016) (discussed above) were used to design the broad framework of the network for used aviation oil. Thereafter, ‘nodes’ and ‘performance indicators’ were identified. The guiding principal or ‘objective’ of the network was to improve the post use management of aviation oil for the Indian aviation sector.

4.5 Reference Model Design: Identifying Nodes

New age environment conscious societies focus on production technologies that reduce pollution in measurable manner. Therefore, designing a comprehensive reverse supply chain network model for reclaimable product like aviation oils required knowledge of collaborative re-processing systems, legal frameworks, and availability of environmentally safe technology. Theoretically, reclamation uses technology to allow the reinsertion of recycled oil into the pre-manufacturing stage, at minimum cost. The operational challenge therefore was to develop techniques in which business development and environmental security can be amalgamated as an objective. The approach to meeting this objective was to re-define the structure and flow of the existing supply chain, by acknowledging the environmental concerns associated with waste and optimizing resource utilisation.

Therefore, the first step was to identify all factors that could help increase collection of used oil, reduce wastage, adulteration and transportation cost. With the objective to help extend the life of the lubricants and reduce the cost of the purchase of fresh base oil. Optimising the reverse supply chain, in terms of transportation and processing cost was the next and final step.

Traditionally, the four main activities for any reverse logistic network for waste handling includes the undermentioned activities. These activities that monitor the flow of material within the network are termed as the nodes. The scope of activity of each node and their relative position in the RSC network is as shown in the figure 4.2. Joanna Daaboul in his research paper 'Reverse Logistics Network design: A Holistic Life Cycle Approach' has discussed a similar movement of recyclable products (Joanna Daaboul, 2014). The proposed RSC network would constitute of the following activities: -

I. Method of **gate-keeping**.

II. **Collection** procedure

III. **Sorting** procedure.

IV. **Transporting** and **Recovery** path.

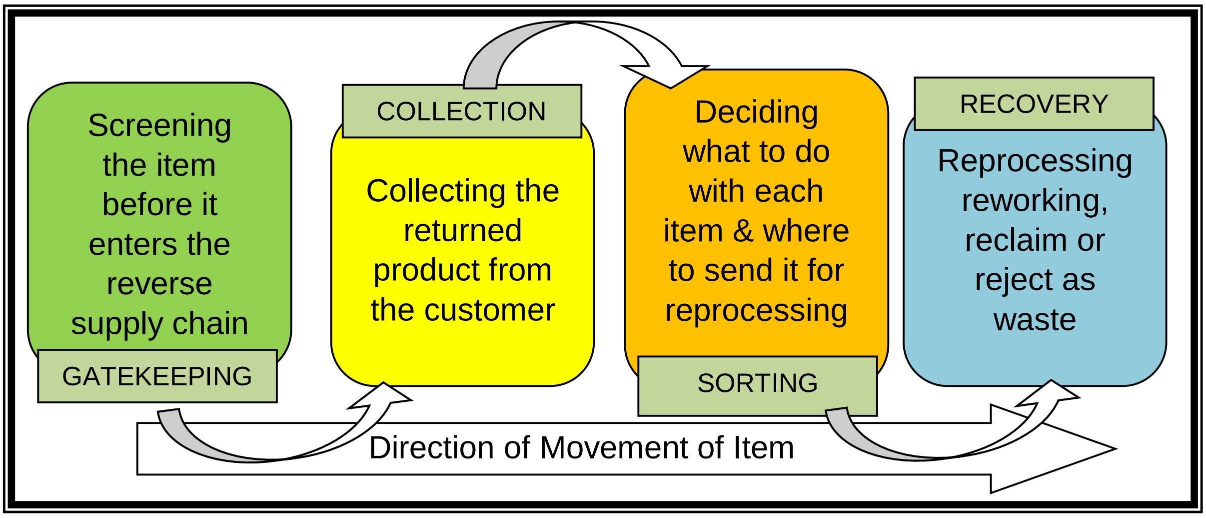

Figure 4.2: Nodes and its Functions (Reverse Supply Chain)(Joanna Daaboul, 2014)

The material flow diagram for the Reverse Supply Chain w.r.t. used aviation lubrication oil with nodes and functions is as shown above.

4.6 Reference Model Design: Recognizing Variables

Like all transport and service sector industries, the aviation industry also uses a wide variety of oils like hydraulic and engine oils for its operations. Routine maintenance activities on aircraft and equipment generate large quantities of waste oil. Most European and American nations use modern technologies, to recycle this waste oil, thereby not only saving precious oil but also reducing pollution. Motivated by this, and supported by strict government policies, many countries have institutionalised mechanisms that promote collection and reclamation of used oil. From literature review, it is evident that the development of a robust network for post use management of used oil can increase the reuse of used oil in formulation of new oils. The efficacy of the network can be determined from the percentage change in collection volumes for re-use and concurrent reduction in environmental damages.

From the literature review and the opinions of industry experts, it is evident that most reverse supply chain researchers consider the RSC network design problem as being that of **gate-keeping, collection, sorting, transportation and recovery (disposal)** (Joanna Daaboul, 2014). The main decisions parameter for the network being: - optimising allocation (quantity) and location (distance of reprocessing facilities) tables against cost and time (refer Chapter 2, Literature Review).

On a similar count, the reverse logistics networks design problem for aviation oils also starts with identifying the "**most used**" aviation oil based on procurement and consumption quantities. Thereafter, estimating the quantities of waste oil being generated at the identified locations and designating the site where it can be safely reclaimed. Therefore, the first step towards designing the network flow included the following estimates: -

I Identifying the "**most used**" aviation oil based on procurement and consumption quantities.

II Estimating the **quantities of waste generated** for most used oils.

III Identifying **reclamation sites**

4.6.1 Estimating Waste Generation

Civil Aviation Sector

Since the year 2000, the Indian civil aviation sector has expanded rapidly. The number of commercial airline operators have increased their fleet size with the induction of modern aircraft. Concurrently, a number of smaller companies have also started commercial operations with small aircraft for air charter services. For maintaining these aircraft, the DGCA has issued licences to technical organisations to undertake scheduled servicing on aircraft. The licences are issued under different categories, which include: -

- ✓ Base Maintenance: - Aircraft maintenance activities carried out in large aircraft hangars with special tools. These are usually carried out by a third party under licence from the manufacturer, the operator and include scheduled activities like major servicing, annual checks, etc (Dviation, 2018).

- ✓ Line Maintenance: - This generally refers to minor, unscheduled or scheduled maintenance carried out on aircraft that occurs at, or near, the gate or terminal (tarmac), launch area, ready area, hardstand or alert area. This is the basic level of maintenance and is limited by basic ground support equipment. It is usually carried out by the operator (Dviation, 2018).

According to the DGCA (DGCA, 2017) and the international airline industry online directories website airlineupdate.com (Ellis, 2017), the following organisations in India provide Maintenance, Repair and Overhaul (MRO) services. The details of the organisations, locations and capabilities/ approvals are listed at table 4.1 below: -

LIST OF CIVIL MROs IN INDIA

Sl No	Name	Location	Approvals	
			3-party Base Maintenance	Engine
1	Air India Engineering Services Ltd (AIESL)	Mumbai/ Delhi/ Nagpur/ Kolkata/ etc	A 319/320/321 B 747/	CFM/ GE/ PW
2	Air Works India (Engg) Pvt Ltd	Delhi/ Mumbai/ Hosur	ATR 42/72 A 320/ 340	--
3	Cochin International Aviation Services	Cochin	B737/ A320	--
4	GMR Aero Technic	Hyderabad	A 319/320/321 ATR 42/72 B 737-600	--
5	HaveUs Aerotech India Pvt Ltd	Delhi/ Dubai	Wheels & Brakes	CFM Jet Engines
6	Indamer Company Pvt Ltd	Mumbai	Bell/ Agusta/ Dauphin/ Sikorsky Helicopter	--
7	Varman Aviation Pvt Ltd	Bengaluru	--	Piston Engines

Table 4.1 List of Major MRO Servicing Large Commercial Aircraft
(Source: http://dgca.nic.in/firms/firm_ind.htm)

The top two aircraft MROs functioning in India are Air India Engineering Services Ltd (AIESL) and GMR Aero Technic, Hyderabad (GIDB, 2020). They undertake major servicing on the airframes/ hydraulic systems of large commercial aircraft belonging to Boeing, Airbus and ATR (a twin-engine turboprop aircraft manufactured by French and Italian company 'Aerei da Trasprto Regionale') fleets. The maintenance philosophy and industrial practices of these two organisations could be considered as benchmark for Indian aviation industry. These establishments also have the approval of DGCA and other international certification agencies. Further, as one of the concern is from the public sector and the other from the private sector, the opinions expressed by the management and engineering practices adopted by these business firm were considered to be represent industry standards for India. Hence these organisations were shortlisted for assessing relevant data on management of used aviation oil at MRO level.

Concurrently, formal interviews were also conducted with senior functionaries of Air India, Indigo Airlines and Jet Airlines for collecting the required data with respect to airway side operations. These airlines were selected as their fleet size is more than 100 aircrafts each (DGCA, 2017). These three companies collectively had a market share of about 64.1% of the domestic passenger traffic for the year 2017-18, i.e. Indigo 36.7%, Jet Airlines 15.0% and Air India 13.1% (DGCA Air Transport-II, 2019). Hence, maintenance staff of these organisations were contacted for collecting relevant data.

Defence Aviation Sector

Similarly, the Indian Air Force (IAF) has over 50 bases across India of which around 40 can be classified as major bases (IAF, GoI, 2018) where aircraft maintenance and repair activities are carried out round the year (Dutch Aviation Society, 2020). Out of these major bases, 20 are located in northern sector, comprising the states of Jammu & Kashmir, Punjab, Himachal Pradesh, Haryana, parts of Rajasthan, Uttar Pradesh and Madhya Pradesh (Pike, 2020). The chief operations officers/ chief engineering officers of all twenty station were requested to provide inputs on the various decision parameters concerning the used oil management practices in IAF. The replies/ comments/ opinion rendered by these functionaries provided important information about the used aviation oils in defence aviation.

Data Collection

Primary data collection and analysis represent the fundamental activities in any research work. For this research, the primary data includes the availability (volume, quality and reliability) of raw material (waste oil in this case). Therefore, the first step was to identify the most used oil and its annual procurement by the airlines. Towards this a survey was conducted to collect primary information. The method used included: -

(a) **<u>Direct Interview/ Distribution of Questionnaires</u>:** Personal involved directly in airlines operations/ maintenance and procurement of consumables were interviewed or sent questionnaires by post or email. The method of collecting data included; by personal interviews or by distribution of questionnaire. The sample of the questionnaire distributed to the Indian Air Force unit level functionaries and the commercial airline operators are placed as **Appendix A1 and Appendix A2** respectively.

(b) **<u>Content Analysis</u>**: In few cases a particular type of oil was being purchased centrally and consumed at multiple location. Therefore, the interviewee or the person responding to the schedule was not completely aware of the global data. In such cases, the data on annual purchase in respect of the company/ organisation was obtained by analysing the provisioning/ purchase tender floated by the organisation. The quantity stated in the tender documents was assumed as the annual consumption for the company.

The survey collated the following information from various sources: -

✓ Hours flown by the airline (Aviation, Hand Book on Civil Aviation Statistics: Table 8, 2017-18).

✓ Types of oils (hydraulic and engine) used (from the aircraft manufacturers website and questionnaire)

✓ Occasions / frequency for change (from aircraft maintenance manuals)

✓ Locations where aircraft are serviced and oil changed from the Directorate General of Civil Aviation (DGCA) website.

Empirical Formula

Theoretically, the quantity of waste oil generated by each operator can be calculated using the undermentioned empirical formula. The quantity of waste oil generated by each airline should be proportional to the quantity of oil purchased and total hours flown by all the aircraft of the company.

Waste Generated α Oil Purchased

Empirical Equation for Aviation Oil

$$Q_w = \sum_{n=H}^{n=0} \int (Qf - (Cb + Ch)Qf)$$

Where: -

Q_w	Quantity of waste generated
Q_f	Quantity of fresh oil purchased
C_b	Co-efficient of burnt oil *
C_h	Co-efficient of handling losses
H	Operating hours of oil

* average per hour oil consumption is suggested by aero-engine manufacturers. Oil consumption pattern of few commercial engines is as shown below (abstract from Boeing service manual) in figure 4.3.

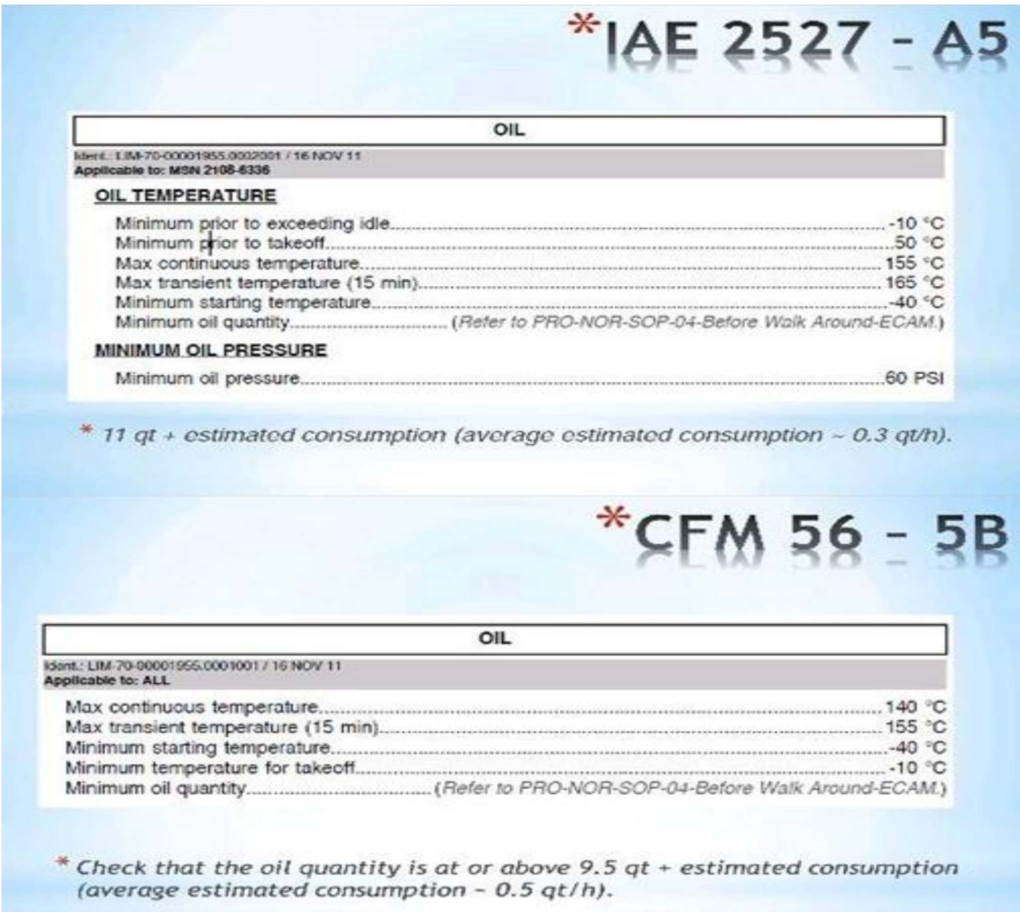

Figure 4.3: Oil Consumption, aircraft engines (Source: Boeing 2015)

The empirical equation projects the net quantities of waste oil which is expected to be generated at each aircraft maintenance site. Therefore, the same quantities of waste oils should be available for the reclamation recycling/ re-refining plant.

Open source commercial documents like tender notice, press release on long term purchase agreements, etc was used to acquire the following data: -

(a) Volumes of waste generated.

(b) Potential to recycle waste.

(c) Relative location of the MROs discharging the recovered materials.

(d) Location and relative distance of the reclamation units.

4.6.2 Ascertaining Reclamation site

The Indian aviation sector has a very wide demographical spread. There are over 400 airports across the length and breadth of the country with over 125 of them receiving regular flights. However, aircraft maintenance activities are base dependent and centres around large operational bases or MROs which have sufficient infrastructure. High volumes of used aviation oil is generated from these bases only. Information on the locations of these sites was acquired from the website of the Indian Air Force (i.r.o. military bases) and Ministry of Civil Aviation (i.r.o. civil aviation) across the country. Similar information on the location of oil reclaimers was gathered from the websites of State Pollution Control Boards. The information was pieced together to estimate the transportation effort and cost involved in moving the used oil to the reclamation site. The list of locations in north India where used aviation oil is generated and sites where it can be processed in discussed in Chapter 5.

4.7 Reference Model Design: Analysing Performance Parameter

The process of reclamation represents a cohesion of various activities that include, the process of collecting and segregating of used materials, products, or components, transporting them to the correct agency and activities related with the reclamation process. The process also includes the cost of reclamation and waste disposal in accordance with local regulations. Thus the network of all activities connected with reclamation should be in sync so as to provide a valuable reclaimed product, which cost's less than the value of original product.

Performance evaluation is an iterative method to determine the efficiency and/or effectiveness of an existing system, or to compare competing alternative systems. Performance parameters are also indicators that are used to measures the productivity of the proposed design, in terms of yielding the best result for the desired objective in-case of designing new processes. Traditional supply chain performance measures include: -

(a) Customer satisfaction in terms of service and/ or responsiveness

(b) Cost of operation and/ or saving in revenue.

Accordingly, the measurable performance indicators for each node as identified from literature review and section 4.6 above, alongwith their associated variable for the proposed network is tabulated below: -

Node	Variable/ Decision Parameter	Performance Indicator (PI)
Gate-keeping	Financial gain	▪ Volume of waste generation
	Environmental gain	▪ Avoid spillage
Collection	Volume	▪ Net purchase ▪ Consumption ▪ Net collection
Sorting and Transportation	Market analysis	▪ Total mass of useful product ▪ Total mass of waste product
	Reclamation site	▪ Distance to site ▪ Volume ▪ Mode/ cost of Transportation
Recovery	Energy	▪ Total energy consumed ▪ Total material consumed
	Waste generation	▪ Hazardous/ toxic waste ▪ Cost of disposal
	Cost	▪ Financial gains

Table 4.2: Relationship Matrix Nodes, Variable, Performance Indicator

4.8 Designing the Network

The starting point for any design problem is its theoretical understanding and thereafter collaborating it with physical market data. The theoretical arrangement of nodes and factors that influence its effectiveness as mapped in the theoretical model presented at Table 4.2. This arrangement was then evaluated for applicability for used oils of aviation industry using expert advice. However, during the process of the assessment of the proposed network with data and knowledge acquired from market survey, it was evident that there were many differences in the theoretical understanding of model and practical arrangement of nodes in Indian context. The boundaries of functional responsibility, activity and role of the node were not distinctly defined in many organisations. The functions of the nodes often overlapped each other or carried out by agencies outside a single organisation. Therefore, the nodes were redefined and their nomenclature changed to reflect the current arrangement in the market. The new nomenclature of the nodes and their function in the network was mapped as follows: -

A **Collector**. responsible for the gate-keeping and collection activities.

B **Sorter**. responsible for sorting different oils as per type.

Transporter. responsible for transporting the oil to the correct location as per the type of oil and reclamation technology at the plant.

D **Reclaimer**. responsible for recovery activities (reclamation)

E **Quality Controller**. responsible to ensure maximum recovery and quality of recovered base stock

Similarly, the decision parameters for evaluating the performance of the network were also re-worded to correctly reflect the existing arrangement in the industry and the logistic setup in India. The decision parameter and the scope of the related performance indicator was redefined as follows: -

I. **Total Cost**. Includes cost of transportation facilities, purchasing activities and stocking requirements of the network

II. **Recycling Rate**. Reflects the service level of the entire network and the percentage of recycled material produced from the product, using the reverse flow rate.

III. **Life Cycle Assessment**. Indicates the environmental impact of the logistics network and reflects the savings in energy, fresh water, new chemicals/ materials, etc. It also indicates the level of waste/ toxic emission and carbon footprint of the entire process.

Revised relationship matrix between nodes, variable and performance indicators is shown in table 4.3 below: -

<table>
<tr><th>Nodes</th><th>Variable/ Decision Objective</th><th>Performance Indicator (PI)
(Yes/ No criteria)</th></tr>
<tr><td rowspan="2">Collector</td><td rowspan="3">Total Cost</td><td>Cost of Collection</td></tr>
<tr><td>Cost of Stocking Facilities</td></tr>
<tr><td>Sorter</td><td>Applicability of regulation/ Directives/ Policies</td></tr>
<tr><td rowspan="2">Transporter</td><td rowspan="2">Recycling Rate</td><td>Cost of Transportation</td></tr>
<tr><td>Quantities in Transit</td></tr>
<tr><td>Reclaimer</td><td rowspan="3">Life Cycle Assessment</td><td>Energy saving/ Reclamation Percentage</td></tr>
<tr><td rowspan="2">Quality Controller</td><td>Generation of toxic waste</td></tr>
<tr><td>Carbon footprint</td></tr>
</table>

Table 4.3: Revised relationship matrix

The proposed reverse logistic network flow chart for used aviation oil with designated nodes is depicted below as a schematic flowchart (refer figure 4.4).

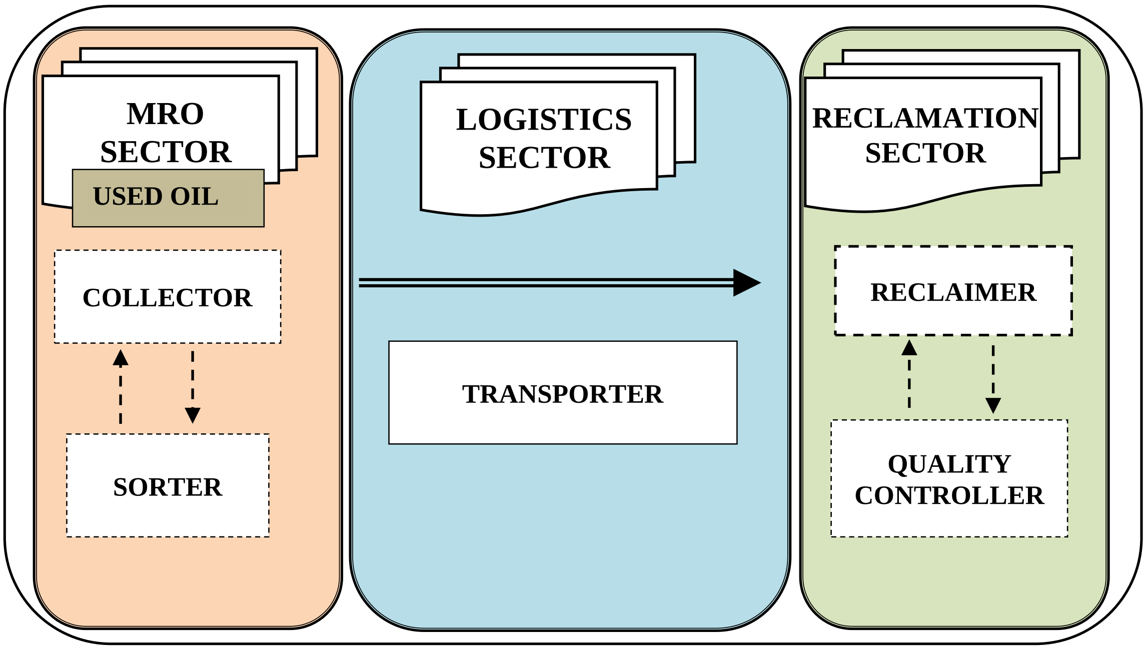

Figure 4.4: Arrangement of Nodes in Material Flowchart for Used Oil

4.9 Evaluating the Network using Analytic Hierarchy Process

Evaluating the design of any new logistic supply chain network is the greatest challenge for any researcher. Especially in a scenario where many variables like, quantities in transit, net financial gain to consumer, etc, may not be immediately known. Therefore, for the purpose of assessing the performance of the logistic network, the relationship matrix has to be converted into measurable comparisons of options. Each decision criteria (nodes) has to be assigned multiple alternatives (performance indicators). Then use the judgment of experts to find the best solution for the problem, from a given set of alternatives. In this appraisal process, each decision criteria (problem) with its set of solution (performance indicator) is put-up to a panel of experts, who in their prudence, assign value to each option, through a pairwise comparisons of alternatives. The results are then weighed against each option to find the best solution. Such scientifically designed evaluation techniques are routinely used to evaluate solutions and support complex decision making process. The Analytic Hierarchy Process (AHP) is one such tool designed by Thomas L. Saaty. It seeks to provide a systematic solution to a multiple criteria decision-making problem.

The Analytic Hierarchy Process (AHP) is an effective tool for analysing complex problems and arriving at a balanced decision. It helps to choose the best solution by assigning priorities and systematically weighing the various options. It reduces the complex problem into a series of pairwise comparisons. The response to each comparison is obtained on a nine-point Likert Scale. It then synthesises the result according to the opinions/ inputs received from the domain experts. The AHP helps in capturing both the subjective and the objective characteristics of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus, reducing the bias and normalising the decision-making process (Saaty, 2008). The computations made by the AHP may appear to be guided by the decision-maker's experience. Therefore, a method of group decision is used whereby a small number of domain experts with slightly varying experience and skill sets are asked to opine on the same set of comparatives (Z Srdevic, 2011). This process further minimises the risk of negligent, incompetent or irresponsible opinions of individuals by calculating the geometric mean of responses. This removes inconsistency by incorporating two measures which are the consistency ratio and Eucidean distance (Z Srdevic, 2011, p. 534). The AHP obviates the requirement of perceived sampling errors during hypothesis testing (Kothari, 2004, p. 158).

Further, the AHP is not a random sampling theory, therefore, the requirement of undertaking tests of significance like Sandler's A-test, for validity, reliability and practicality, is not required. Further, the AHP also does not initialise the outcome as a hypothesis, therefore, standard parametric/ non-parametric tests like the z-test, t-test, X^2-test and F-test are not required for testing the assumption (Kothari, 2004, p. 195). In a nutshell, the AHP is considered as a tool that is able to translate the evaluations (both qualitative and quantitative) made by the decision-maker into a hierarchically ranked choice for arriving at the best solution. In addition, the AHP is simple because there is no need of building a complex expert system with the decision-maker's knowledge embedded in it.

4.9.1 Identifying Experts: Sampling Technique and Sample Size

Selecting a criterion-based sampling strategy that represents and characterises the global population was an important consideration for this research. As this is a qualitative research, it was important to confirm that the selected sample represents the target population with regard to the demographic and other relevant characteristics. Therefore, the sample size selected for the purpose of collating data, was a specific group of aircraft operators and maintenance crew. The sampling strategy for this research were: -

- ✓ Stratified Purposeful Sampling. In this sampling process, the overall population is first separated in to groups of strata's according to their characteristics (Given, 2008). Therefore, the Indian aviation industry was divided in to two groups; Defence aviation and civil aviation operators having independent maintenance set-up. Number of entries in the groups were restricted to twenty from Defence and seven from civil aviation. Selection was based on volume of annual business executed by each identity.

- ✓ Purposive Sampling. It is a strategy of sampling wherein the researcher relies on his own judgment for choosing the members of the population to participate in the survey/ study (Tim, 2014). Top functionaries and shop floor supervisors at aircraft maintenance site (MRO), who were directly involved with the procurement, use and logistics of lubricants were selected and interviewed. The sample size was restricted to on-site respondents only.

- ✓ Snowball or Chain Sampling. When a researcher interacted with the repair organisation for the first time, it was difficult to correctly identify the precise individual has a complete knowledge of the operations. Therefore, snowball or chain sampling process was used. Chain-referral sampling is a non-probability sampling technique of study where a known respondent refers or nominate another potential primary data source, who can provide better insight on the subject. In this sampling method, the number of person contacted by the researcher may grow but the number of respondents may be restricted due to individuals' expertise on the subject. In this case, the respondents were identified from amongst operators, regulators and management functionaries with knowledge of aviation, pollution control and supply chain management. Therefore, the sample size was restricted to only 42 experts.

The sample size was kept small for the aviation sector as a previous study (literature review) by Eshtaiwi (Mohamed Eshtaiwi, 2018), established that very large samples are not required for using AHP to analyse issues of aviation industry due to 'cold-called' respondent scenario. Similarly, Jagroop Singh (Jagroop Singh, 2018) used a sample size of only 14 while using AHP to establish factors to reduce fuel consumption in aviation industry. On the basis of these theoretical understanding of sampling method, the questionnaire was distributed amongst 42 participants only. The details of the participants are placed at **Appendix A3**. The respondents were classified into two groups, according to their domain expertise: -

(a) Group I: Users of the product, including the maintenance and provisioning heads from the Indian Air Force, Air India, Indigo Airlines and Airbus training centre (26 experts). Questionnaire as shown in **Appendix A4** and **Appendix A5** was distributed to the participants in hard and/ or soft copies.

(b) Group II: Members/ senior functionaries of regulatory authorities like the DGCA and Central Pollution Control Board (16 experts). The questionnaire was distributed to these participants.

4.9.2 Assigning Weights to the AHP Model

In order to optimise the proposed RSC for used aviation oil, with use of AHP, the problem is disintegrated into a set of rationalised criteria and alternatives for each the main objective. This process of identification of alternatives was discussed in the section 4.8, above. Accordingly, a relationship matrix as shown below was designed. The main objective of the AHP process was to seek the best answer for the question; '<u>Should used aviation oil be reclaimed or incinerated?</u>". The steps adopted for formulating the comparison matrix are enumerated below: -

Step 1. Conversion of objective into hierarchy framework. The first step is to establish the relationship between the objective and various factors/ sub-factors which are likely to influence the decision. The step includes identifying all the alternatives for the chosen objective and selecting the decision criteria for the set of alternatives. The multi-criteria decision making matrix for the primary objective and conditional objectives alongwith related evaluation criteria and matching alternative for the process is shown below as tables 4.4 and 4.5 respectively.

GOAL	CRITERIA	ALTERNATIVE
Should used aviation oils be Reclaimed or Incinerated ?	Cost of Collection and Handling	Reclaim or Incinerate (Burn)
	Cost of Sorting and warehousing	
	Transportation Cost	
	Reclamation Cost	

Table 4.4: Decision Matrix-Primary Objective (Main factors)

The criterion for the primary objective shown at table 4.4 above, was evaluated with feedback from academia/ supply chain experts and the additional 'Alternative – Criteria' relationship matrix was added to match the number of measurable performance indicators, for each goal, discussed at section 4.8 above. In this group decision making process, the criteria and alternatives must be determined before designing the relationship matrix. The words ‘factors, objective and goal’ and ‘choice, criteria and alternative’ are interchangeable and frequently used in describing the process.

GOAL	CRITERIA	ALTERNATIVE
Collection	Introduce regulatory mechanism	Maximise collection at minimum cost
	Use of specialised tools	
	Enact training and skilling program	
	Motivation to reduce unsolicited disposal	
Sorting	Inventory handling cost	Reduce segregation and handling cost
	Storage policies	
	Warehousing effectiveness cost	
Transportation	Transit Cost	Maximum quantity at minimum cost
	Transit Quantity	
Reclamation	Economy of Efforts	Maximise recovery at minimum environmental cost
	Regulation on disposal of waste	
	Availability of Environmentally Safe Technology	

Table 4.5: Decision Matrix-Conditional Objective (Sub-factors)

The hierarchy structure of the decision-making problem as generated using the ‘Super Decision’ software is shown below as figure 4.5. The level 1 is the goal of the problem which is to be analysed. Level 2 is the multi-criteria level, which contains the factors likely to influence the goal. While level 3 depicts the sub-choices for each criterion. The last level depicts the alternative choices (inferred decision) for the main goal.

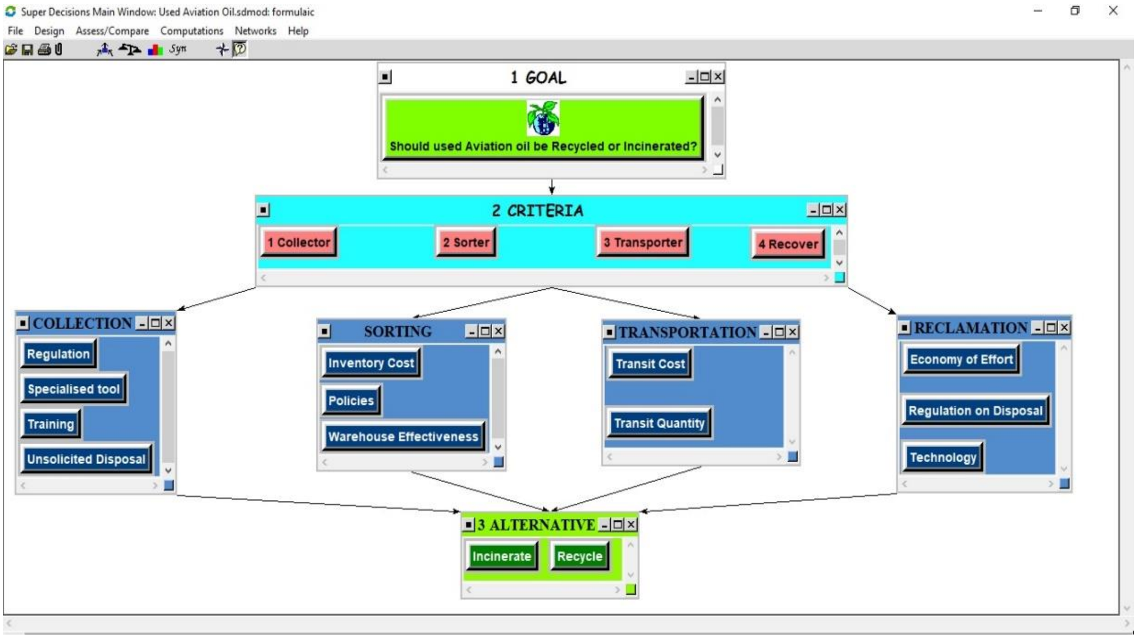

Figure 4.5: AHP structure generated using 'Super Decision' software

Step 2. Empirical data collection using the questionnaire. A total of 42 domain experts were chosen for the purpose of purposive sampling. They belonged to the field of aviation, supply chain management, conservationist from pollution boards and technologist from oil industry with adequate knowledge and experience. The experts were asked to evaluate the influence of each factors/ sub-factors from a set of performance indicators for each query of the survey sheet (refer Appendix A4/ A5). The response to the pair-wise comparison for five objectives and 16 alternatives is recorded using Saaty’s nine-point intensity scale (Saaty, 2008). A total of 19 pair-wise comparisons which were evaluated for each objective, are presented at table 4.6 below: -

Goal/ Objective	Number of Criteria/ Alternative/ Choices 'n'	Number of Paired Comparisons $P = \frac{n\,(n-1)}{2}$
Level 1		
Reclaim or Incinerate	4	6
Level 2		
Collection	4	6
Sorting	3	3
Transportation	2	1
Reclamation	3	3

Table 4.6: Pair-wise comparisons in questionnaire

Step 3. Aggregating Pair-wise comparisons. The response from experts were received according to Saaty's nine-point intensity scale. The judgement preference for recording the response is tabulated below as table 4.7. Each relative value indicates the comparative importance of i^{th} factor compared with j^{th} factor.

Numerical Scale	Precedence for Judgment
1	Equal importance
3	Moderately more importance of one over the other
5	Strongly more important than other
7	Demonstratively more strong than other
9	Extremely more important
2,4,6,8	Intermediary value between adjacent judgments

Table 4.7: Scale of precedence for judgment

Sample matrix of comparison is shown below as Table 4.7.1: -

Question- Which factor has the greatest influence on the efficacy of RSC of used aviation oil? (Expert to mark response in relevant box as per importance.)

Criteria(j)	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9	Criteria(k)
Collection													X						Sorting
Collection																	X		Transportation
Collection										X									Reclamation
Sorting												X							Transportation
Sorting							X												Reclamation
Transportation				X															Reclamation

Table 4.7.1: Sample Comparison Matrix

The weight for the criteria is starts by assigning relative priority to an alternative in a pairwise comparison matrix. Each entry e_{jk} in the matrix represents the importance of the j^{th} criterion relative to the k^{th} criterion. If $e_{jk} > 1$, then the j^{th} criterion is more important than the k^{th} criterion, while if $e_{jk} < 1$, then the j^{th} criterion is less important than the k^{th} criterion. If two criteria have the same importance, then the entry e_{jk} is 1.

The responses received from each expert for each pair-wise comparison is recorded on a tabular sheet as above. Thereafter, the responses for each comparison (judgment) from all experts is aggregated using geometric mean. Saaty recommended the use of geometric mean to preserve reciprocal property of data. Let the resultant filled-up matrix appear as follows: -

Criteria	**C1**	**C2**	**C3**	**C4**
C1	1	4	8	1
C2	1/4	1	3	1/4
C3	1/8	1/3	1	1/6
C4	1	4	6	1
Sum	2.375	9.333	18	2.417

Table 4.7.2: Sample Filled Matrix

The data analysis procedure involves extracting the data collected from the pairwise comparison matrix in respect of each respondent. The data is then normalised by dividing the value of each response in the pair-wise comparison table with sum or responses for the particular column. This gives the geometric mean of all responses. The formula of calculating the normalised cell value is as shown below: -

$$f_{ij} = \frac{e_{ij}}{\sum_{j=1}^{n} (e_{ij})}$$

where 0 < e_{ij} <1 and f_{ij} is the new cell value (final weight of each choice) of the normalised matrix.

Next, the criteria weight vector or entropy for each alternative is calculated by averaging the entries on each row.

$$W_j = \frac{1}{In(n)} \sum_{i=1}^{n} f_{ij} \, (Inf_{ij})$$

This normalised criteria weight vector (W) is also called priority vector. The priority vector represents the relative weight of the given choice/ alternative from amongst the other choices for the given objective. Eigen Vector for the sample matrix calculated using the above formula is shown below in the last column: -

Criteria	Normalised Cell Value				Total	Average W_j
	C1	C2	C3	C4		
C1	0.421	0.429	0.444	0.414	1.708	0.427
C2	0.105	0.107	0.167	0.103	0.482	0.121
C3	0.053	0.036	0.056	0.069	0.214	0.054
C4	0.421	0.429	0.333	0.414	1.597	0.399

Table 4.7.3: Sample Eigen Vector for Filled Matrix

The term Weight Vector is used to describe the importance of the given criterion. The higher the value of the vector the larger is its weight, i.e. the option associated with greatest vector in the decision making process is the best alternative. In the given matrix factor C1 is the best alternative suggested by experts.

Step 4. Check for Consistency of Data. AHP is an opinion based assessment system for choosing the best solution. Therefore, there are possibilities of experts being inconsistent in their judgments, while grading multiple pairs of comparisons for same objective. For example, from the sample matrix 4.6.1, four criteria were considered. Ideally if the decision maker evaluates that the first criterion C1 as *slightly* more important than the second criterion, while the second criterion C2 as *slightly* more important than the third criterion and the fourth criteria as least *important*. Than the resultant vector weight assigned to them should also be in the same order i.e.

$$W_1 > W_2 > W_3 > W_4$$

However, inconsistency arises if the decision maker evaluates by mistake that the third criterion C3 as equally or more important than the first C1 and second criterion C2, while assessing C2 to be more important than C3. Thereby making C3 to be more important than C1 and C2, but C2 to be more important than C3. A consistent evaluation is therefore required to ensure balanced grading.

The consistency of the recommendations made by the decision makers in AHP is checked by using the following technique;

First compute λ, which is the average sum of the product of each element of the row of the pair-wise matrix with each element of the weight vector column.

$$\lambda = \sum_{i=1}^{n} C_{v_{i1}}$$

Where $C_{v_{i1}}$ is the consistency vector

$$C_{v_{ij}} = \sum_{i=1}^{n} \frac{1}{W_{i1}} \sum_{j=1}^{n} C_{ij} W_{ij}$$

Then derive *Consistency Index* (*CI*) by following formula, where n is the size of matrix, *four* in this case.

$$\text{CI} = \frac{\lambda - n}{n-1}$$

Finally, inconsistency is checked by determining the *Consistency Ratio* (CR). This check affirms that the CI of the responses are in order of precedence (Jose A Alonso, 2006). It is calculated by dividing the CI with a random number called *Random Index* (RI), which is dependent on the size of the matrix. The value for RI is taken from standard RI table shown below;

Matrix Size	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Table 4.7.4: Values of RI for Small Problems, Adapted from (Saaty T. L., 1980)

Prof. Saaty stated that for perfectly consistent decisions CI=0, but small variations are acceptable. As long as results are with 10% of random index, the responses can be considered as consistent.

$$CR = \frac{CI}{RI} < 0.1$$

Criteria	**C1**	**C2**	**C3**	**C4**	**Average (W_{ij})**	**Consistency Vector ($C_{v_{ij}}$)**
C1	1	4	8	1	0.427	4.063
C2	1/4	1	3	1/4	0.121	4.036
C3	1/8	1/3	1	1/6	0.053	4.009
C4	1	4	6	1	0.399	4.079
Sum	2.375	9.333	18	2.417	$\lambda =$	4.047
	Consistency Index CI =					0.016
	Random Index from Saaty's Table RI_4 =					0.90
	Consistency Ratio CR (CI/RI_4)=					0.017

Figure 4.6: Sample Check of Consistency in response

In the stated example, since the consistency ratio is 1.7 %, the weightage assigned by the experts can be considered as consistent. Since the highest weight was assigned to criteria C1, it can be assumed to the best alternative for the given problem.

Step 5. Presenting Global Data The weight of all paired comparisons are tabulated and priority weight aligned with each criterion. Thereby, assessing the influence of the given factor on the overall efficiency of the Reverse Supply Chain. The results are discussed in the next chapter.

4.10 Framing the Questionnaire

In order to evaluate each scenario against the chosen set of performance indicators, a comparison between various alternatives is required. Each set of questions were framed to evaluate specific relations between various alternatives. Respondents were requested to offer their valuable opinion and assign weightages to choices enlisted under alternatives for each question. For example, if they reasoned and considered a particular choice (Ex 'Factor A') as more important than another choice (Ex 'Factor B'), for the given question, then they were requested to assign higher weightage to the given choice. Respondents were required to mark with a cross 'X' on the sliding scale. A schematic diagram of the weighed scale discussed earlier was adapted for this questionnaire, modified table is shown below as table 4.8: -

Choice A	"Extremely Important "(ExI)	"Strongly Important"(StI)	"Moderately Important "(MI)	"Slightly Important "(SI)	"Equally Important "(EI)	"Slightly More Important" (SMI)	"Moderately More Important"(MMI)	"Strongly More Important" (StMI)	"Extremely More Important" (ExMI)	Choice B
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Table 4.8: Weighed Scale for questionnaire

4.10.1 Brief Introduction for Respondents

The following passage in the questionnaire was used to introduce the topic to the domain experts.

“Reclamation and recycling of used oil is a globally accepted technology in oil industry. European and American nations use recycled oil as base oil to meet at least 40% of their domestic oil requirement (Prof. K. R. Chari, 2013). This is achieved through improvement in technology, firm regulations, user awareness and a robust reverse supply chain. Primary survey of existing practices and data collected from Indian aviation sector indicates that only a small fraction of used oil drained from the aircraft is being returned to store and sold to oil recyclers. Theoretically, larger quantities of used oil can be returned for reclamation, if it is managed properly. The key factors/ criteria which can help maximize/ improve the quantity/ quality of used oil were identified from existing reverse supply chains (RSC) for polluting, re-usable and recyclable products. These are; collection, sorting, transportation and reclamation. This survey is aimed to identify and weigh the various factors/ criteria which in your opinion would help optimize the reverse supply chain for reclamation of used aviation oil. The schematic arrangement of various factors that are likely to influence the RSC for collection of used aviation is depicted in figure 4.7. The objective is to decide between collecting for reclamation or incineration, from environment and revenue stand point.

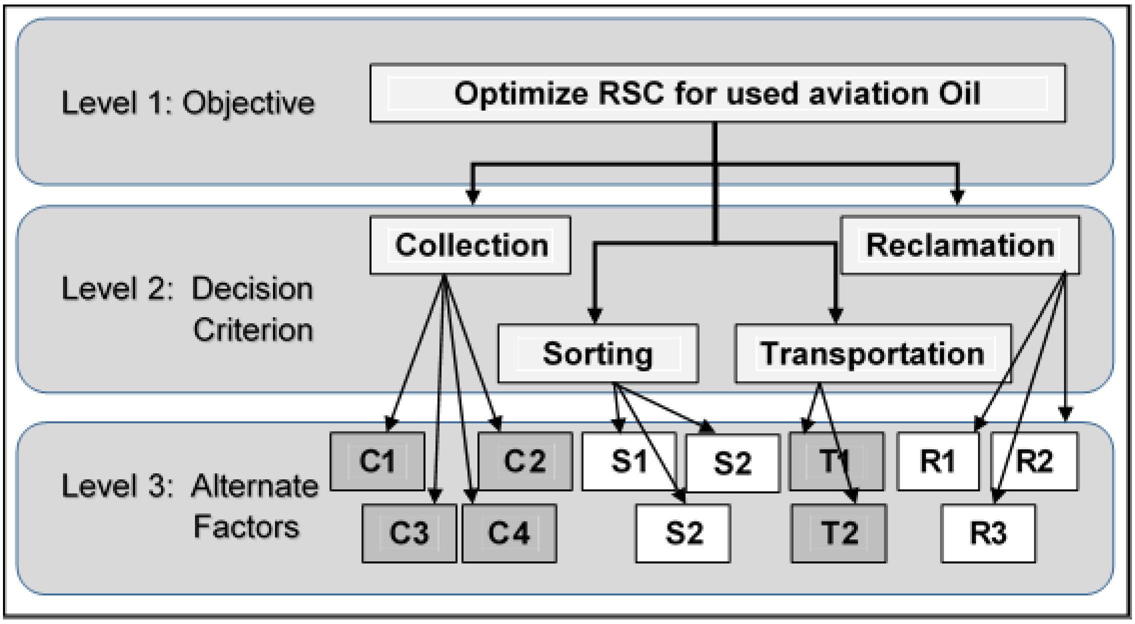

Figure 4.7: Decision Levels- RSC for aviation oil

4.10.2 Questions to Experts

Question-1. Optimizing the Supply Chain: The supply chain of used oil collection for reclamation originates from the Tarmac/ Hangar/ Shop floor/ MRO/ etc where technical activities on oil system are carried out. The chain culminates at the reclamation plant. The quantity and quality of used oil collected and sent to store/ recycler dependents on various factors including the appreciation of personal carrying out these activities. The following factors affects the supply chain for similar recyclable and polluting products.

Collection. The scope of this criteria encompasses all technical activities (and technicians) involved in the process of collection of used oil drained from the aircraft during repair/ servicing. The quantity and quality of used oil collected from the repair site depends on the involvement and understanding of the technicians.

Sorting. Sorting is the process of segregating different types of used oil so that it is not contaminated with other types of oil during transportation and storage. Sorting includes all activities and issues like regulations, warehousing, inventory management, etc that may affect the purity of collected oil and its unsolicited disposal. Proper sorting leads to better remunerations for the product.

Transportation. This criterion includes all activities that affect the process of physical transportation of used oil from the service station to the store/ reclamation plant. Correct transportation policy can not only prevent wastage, reduce handling losses, reduce transportation cost and prevent further contamination of used oil.

Reclamation. Recovery of used oil is technology driven and governed by many regulations including concerns for clean environmental. Reclamation reduces waste generation, reduces pollution and increases life of product. It also generates additional revenue for the exchequer.

From economic and environmental consideration maximum quantity of used oil should reach the oil recyclers, reclaimer. Therefore, in your opinion, which factor (criteria) amongst the set of alternatives stated below, have greater **influence on deciding the efficacy of supply chain of used oil**, for its journey from aircraft to reclamation plant? Mark with a cross 'X' on the sliding scale.

Factors - Improving collection, Reducing wastage, Preventing contamination and Reducing transportation cost.

Weightage scale: Set 1

COLLECTION	**ExI**	**StI**	**MI**	**SI**	**EI**	**SMI**	**MMI**	**StMI**	**ExMI**	SORTING
	1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**	
	← **Factor A**					**Factor B** →				

Weightage scale: Set 2

COLLECTION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	TRANSPORTATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 3

COLLECTION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	RECLAMATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 4

SORTING	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	TRANSPORTATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 5

SORTING	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	RECLAMATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 6										
TRANSPORTATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	RECLAMATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

<u>Question-2</u>. The quantity of used oil **collected** from the work-station/ repair site may be subject to many factors. According to inputs received from servicing staff and shop floor management the volume of oil returned to store may be influenced by the following factors: -

Regulations/ directives/ policies on accounting of each variety of used oil drained from aircraft as different inventory

Training of technicians and storekeepers working on/ supervising the repair activity on safe handling of used oil

Availability of **specialized tools** and shipping containers for draining and transporting the used oil improve the quantity of collection, by minimizing wastage, spillage and handling efforts

Disposal instruction to prevent unsolicited use of used oil within the workshop/ organization like using it as anti-rust painting, lubricating oil on tools and equipment, as cleaning agent, etc.

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on the **collection** of used oil recovered/ drained from aircraft and thereafter returned to store? Mark with a cross ‘X’ on the sliding scale.

Weightage scale: Set 1

REGULATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	TRAINING
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 2

REGULATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	SPECIAL TOOL
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 3

REGULATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	DISPOSAL
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 4

TRAINING	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	SPECIAL TOOL
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					→ Factor B				

Weightage scale: Set 5										
TRAINING	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	DISPOSAL
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 6										
SPECIAL TOOL	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	DISPOSAL
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

<u>Question-3</u> The **sorting** process affects the quality of used oil returned to reclaimer as contamination by other types of oil/ fuel/ water/ grease/ etc may result in lower recovery rates. According to experts from reclamation sector, proper sorting can improve the recovery rate and reduce sector's carbon footprint. Factors which influence the sorting process are listed below: -

> **Regulations**/ directives/ policies on inventory management of used oil drained from aircraft.
>
> **Warehousing** effectiveness - which is defined as the material handling capability and warehousing strategy of a store.
>
> Inventory **Carrying Cost** - which includes all expense towards the management of inventory in storage.

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on the sorting process at the warehouse level? Mark with a cross 'X' on the sliding scale.

Weightage scale: Set 1										
REGULATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	WAREHOUSING
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 2										
REGULATION	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	CARRYING COST
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 3										
WAREHOUSING	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	CARRYING COST
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

<u>Question-4</u> The efficiency of **transportation** system significantly influences the performance of any supply chain. According to literature review, the following factors may affect transportation: -

Quantity in transit.

Transportation **distance**

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on the reverse supply chain of used oil? Mark with a cross ‘X’ on the sliding scale.

Weightage scale: Set 1										
QUANTITY	**ExI**	**StI**	**MI**	**SI**	**EI**	**SMI**	**MMI**	**StMI**	**ExMI**	DISTANCE
	1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**	
	← **Factor A**					**Factor B** →				

Question-5. **Reclamation** is technology driven process and governed by many regulations including concerns for clean environmental. According to experts the following factors may influence the through-put of the RSC of oil: -

Availability of environmentally safe **technology** for reclamation of used aviation oil in close proximity of aircraft MRO.

Economy of effort and scale for strategic use commercial resources

Implementation and audit of **regulation** on disposal of waste oil (Hazardous and Other Wastes Rules, 2016).

In your opinion, which factor amongst the set of alternatives will have greater influence on the organisation/ floor manager towards enforcing accounting/ collection of used oil for reclamation? Mark with a cross ‘X’ on the sliding scale**.**

Weightage scale: Set 1

TECHNOLOGY	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	ECONOMY
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 1

TECHNOLOGY	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	ECONOMY
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 2

TECHNOLOGY	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	REGULATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Weightage scale: Set 3

ECONOMY	ExI	StI	MI	SI	EI	SMI	MMI	StMI	ExMI	REGULATION
	1/9	1/7	1/5	1/3	1	3	5	7	9	
	← Factor A					Factor B →				

Complete questionnaire is attached as Appendix A4/ A5. The response from experts was recorded during personal interview or recorded on ‘Google Forms’ over the internet. The responses received from experts and findings of the survey are discussed in the next chapter.

4.11 Objective-wise Summary of Research Methodology

Objective I. To study the existing practices for disposal of aviation oils, in terms of cost recovery and compliance with regulatory mechanism. Also, estimate the quantities of waste oil generated by aircraft.

Research Methodology:

(a) Direct Interview/ Distribution of Questionnaires to personal directly involved in airlines operations/ maintenance and procurement of consumables.

(b) Content Analysis/ estimation using empirical formula

Waste Generated α **Oil Purchased**

Objective II. To develop and validate the inter-relationship of various factors that influence the reverse supply chain for collecting of used aviation oils.

Research Methodology

AHP technique was used to assess the impact of each factor, on the performance of the reverse logistic network. This knowledge is used to improve the functioning of each node and ultimately the efficacy of the entire chain. Analysis of the matrix is as follows: -

- ✓ Identifying functionaries, defining their role and assessing their performance within the RSC.
- ✓ Asking experts to assign weightage to various nodes.

- ✓ Designing the least cost workflow.

- ✓ Recognising operational, policy, regulatory weak links in the network.

- ✓ Identifying the regulatory and policy changes required for strengthening the network and improving revenue generation.

Objective III. To develop strategies to optimize reclamation of used aviation oil in India

Research Methodology

Operations Research (OR) 'Transportation Model' technique was used to: -

- ✓ Match the location of the reclamation facility vis-a-vis aviation MRO's and calculate the load-distances.

- ✓ Calculate 'Truck-out' load and cost.

- ✓ Project revenue generation by reclamation vis-a-vis incineration.

The findings, analysis of the results and contribution of the research is discussed in the next chapter.

CHAPTER 5

AHP SIMULATION AND FINDINGS

5.1 Introduction

According to a research report published by the department of Chemical Engineering, AMU, about 70-80% of base-stock oil could be recovered from waste oil samples collected from various disposal sites in Aligarh (Katiyar, 2011). Similar statistics is quoted by oil experts from various state pollution control boards, according to them, up to 60%-70% base stock (fresh oil) is recoverable from commercially available 'used automobile oil' (MPCB, 2012, p. 5), whereas, over 75% can be recovered from aviation oil as it is relatively less contaminated in comparison to automobile oils. These opinions are based on the fact that aviation lubricants are less likely to be contaminated by water, fuel, dust and other lubricants as they are handled by disciplined technicians working in clearer environment. Therefore, the remuneration likely to be received for used aviation oil could be much higher than that earned from reclaiming used automobile oil.

Further, a study conducted by the US Air Force Regional Environmental Office also brought out that reclamation of used aviation oil not only reduces volume of hazardous waste but also generates ancillary income. The study report (US Air Force Regional Environmental Office, 2000) established that it is atleast twice as profitable to reclaim than incinerate use oil.

5.2 Evaluating Domestic Oil Reclaiming Capacity

As a first step towards suggesting reclamation of aviation oils, a realistic assessment of the oil reclamation industry was conducted. According to open source data compiled from website of various state pollution control boards and Central Pollution Control Board (CPCB, MoEF&CC, 2020), the total reclamation capacity of industries located in states of Haryana, Punjab, Himachal Pradesh, Maharashtra and Gujarat was far exceeded the total used oil generated by oil consumers in this region (MoEF&CG, GoI, 2016). As discussed in section 3.10 earlier, the nation regulation introduced in 2008, mandated collection and reclamation of used oil. By the year 2013, there were over 257 oil recycler with aggregated capacity of over 1.39 MMT (P K Selvia, 2013). However, due to ineffective collection mechanism, sufficient quantities of used oil was not available to sustain the oil recycling industry. Therefore, under pressure from the association of oil reclaimer and in order to bridge the gap between installed capacity and availability of material, the Ministry of Commerce and the Ministry of Petroleum and Natural Gas, started permitting the import of waste/ used oil for the purpose of reclamation since 2014 (Dept of Comm, 2020). The quantity of used/ waste oil imported into the country since 2014 is shown below in table 5.1: -

IMPORT OF WASTE/ USED OIL FOR RECLAMATION IN INDIA

Item	2014-15		2015-16		2016-17		2017-18		2018-19	
27109100 Waste Oil	**Qty (TT)**	**Cost (L ₹)**	**Qty (TT)**	**Cost (L ₹)**	**Qty (TT)**	**Cost (L ₹)**	**Qty (TT)**	**Cost (L ₹)**	**Qty (TT)**	**Cost (L ₹)**
	0.08	4.0	0.09	4.51	0.22	12.11	0.42	608.1	0.4	580.1

Table 5.1 Import of Waste oil for Reclamation, (Source: Dept of Comm, 2020)

From the above statistics it is clear that while India continued importing over 3.3 MMT of lubricating oil annually, it was unable to stimulate the used oil collection ecosystem and streamline the management of use oil. The progressive collection and re-refining targets set by CPCB, could not be achieved for several years. Therefore, the country had to import used/ waste oil, in order to meet the demands of used oil. This Hazardous Waste material which had the potential to offset countries import dependency of base-stock oil continued to be largely wasted and causing pollution. The import of used oil by the government while supported the reclamation industry, de-incentivised the small scale oil collectors and weakened further the waste oil aggregator's supply chain. The detailed analysis of reasons for the low collection of used oil and method to mitigate the shortfall is deliberated latter in this chapter.

5.3 Objective I: Evaluation of Existing Practices (Findings)

Findings of primary survey of the existing practices for post use management and disposal of aviation oils, in terms of quantities of waste oil generated and cost recoveries is discussed in this section.

5.3.1 Cost Benefit Analysis: Indian Used Oil Scenario

In order to check the feasibility of reclaiming used aviation oil, discharged from various types of aircraft, spectrometric analysis of used aviation oil was carried out at laboratories of the Indian Air Force (IAF) and Council of Scientific and Industrial Research - Indian Institute of Petroleum (CSIR-IIP). Similar used engine oil samples were collected from the engine test bed section of Air India Engineering Services Limited (AIESL), New Delhi. The results of the test for few oil samples collected from different location are tabulated below. From the information furnished by the labs, it is evident that level of physical contaminant like metal from engine parts, etc, is very low. The preliminary results, supported the hypothesis that used aviation oil can be reclaimed like used automobile oil. The results also enthused the understanding of re-refining and assured the theory of definite financial gains for organisations from reclamation.

PRESENCE OF SUSPENDED MINERAL IN FRESH AND USED AIRCRAFT ENGINE OIL

Sl No	Mineral	Fresh Oil Sample	Sample S_1	Sample S_2	Sample S_3	Sample S_4
1.	Iron (Fe)	**0.0**	0.0236	0.478	0.279	0.081
2.	Copper (Cu)	**0.1**	0.209	0.241	0.202	0.483
3.	Nickel (Ni)	**0.0**	0	0	0	0
4.	Chromium (Cr)	**0.0**	0	0	0	0
5.	Silver (Ag)	**0.0**	0	0	0	0
6.	Magnesium (Mg)	**0.3**	2.208	2.514	2.369	4.988
7.	Lead	**0.0**	0.109	0.245	0	1.574
8.	Aluminium	**0.0**	0	0	0	0
9.	Beryllium	**0.0**	0	0	0	0

Table 5.2: Spectrometer analysis of engine oil (AF-POL Lab, 2017**)**

Market surveys and data collated from various primary sources also presented certain financial advantages to organisations for adopting better collection and disposal practices for used oil. It was noted from the responses to questionnaire (refers to section 4.6 of previous chapter) that most organisation spent approximately ₹5 to ₹6 per litre, towards manpower and material for safe disposal/ incineration of used oil in accordance with the policies on effluent treatment (Min of Environment, Forest & Climate Change, 2019). On the other side, some establishments also managed to recover about ₹30 to ₹100 per litre by selling used oil to reclaimer. The net worth of used oil could be improved by the organisation by suitable segregation and avoiding contamination/ mixing of different grades of lubricants. The table below shows the financial gains from reclaiming used lubricants.

NOTIONAL PROFIT MARGINS FOR RECLAIMING USED OIL

Type of Used Oil	Selling Price (MRO)	Process Cost	Selling Price Reclaimed Oil	Notional Margins (Reclaimer)
Engine Oil	₹ 30.00 to 35.00	₹ 15.00 to 20.00	₹ 55.00 to 100.00	₹ 10.00 to ₹ 45.00 / litre
Hydraulic Oil	₹ 85.00 to 100.00	₹ 20.00 to 70.00	₹ 125.00 to 210.00	₹ 15 to ₹ 40 / litre
Average	₹ 57.50 to ₹ 67.50	₹ 17.50 to ₹ 45.00	₹ 90.00 - ₹ 155.00	₹ 12.5 - ₹ 42.50

Table 5.3: Price of Used and Reclaimed Oil (Indiamart, 2019)

Information collated from various research papers and market survey brought out that the cost of reclamation of oil varies typically with the type or grade of oil collected and technology used for reclamation. From empirical observations as shown in table 5.3 above it was estimated that the notional financial profits for reclaimer varies from ₹12.5 to ₹42.5 per litre depending on the quality and type of used oil. For the above it was inferred that, collecting used oil for reclamation would make better economic sense for the organisation as against incineration. While incineration leads to pollution and discharge of hazardous material to ground, reclamation leads to additional revenue generation and greening of environment. Table 5.4 validates the financial gains for MRO in support of reclamation.

MANAGEMENT OF USED AVIATION OIL

Loss/ expenditure for disposal of used oil by incineration	**- ₹30**
Profit/ income from sale of used oil for reclamation	**+ ₹60**
Reclamation is **3** times more economical than incineration/ disposal as waste	

Table 5.4: Incineration Vs Reclamation: Cost Benefit Analysis

5.3.2 Estimating Volumes of Used Oil (Civil Operators)

A scheduler as discussed in section 4.6.1 (a) of previous chapter was distributed to experts and functionaries of shortlisted civil aviation organisation. In case of civil commercial aircraft operators, it was observed that most companies were operating aircraft on lease from other organisations. Therefore, detailed data on the purchase of aero-lubes was not readily available with them. Post-use disposal figures were not being maintained by these organisations as no in-house servicing activities were being carried out by them. All types of maintenance activities, including breakdown maintenance were carried out by third party vendors (authorised service providers), hence, they were unable to provide data/ detailed information on used oil disposal. As regards the scope of maintenance and servicing responsibility of airlines, they could only provide data on the purchase quantities of aero-lubes. The main reason for the same was be attributable to the following: -

I. Major servicing like **1C** (18months/ 5000cycles/ 10000Hrs), **2C**, **A-checks**, etc involves major maintenance or servicing activities are required to be carried out on aero-engines/ airframes at fixed intervals. Most commercial airliners outsource these activities to Boeing/ Airbus certified engineering firms in accordance with IATA regulations (IATA, 2017). These servicing activities are not carried out by the operators at their own premises. Only Air India has through its sister company Air India Engineering Services (AIeSL) has aero-engine (hot-bed) maintenance facilities at Mumbai and structure facilities at New Delhi and Nagpur. Therefore, details about disposal action of used aviation oils was not readily known to the engineering/ maintenance staff of operators.

II. Most private commercial airliners (except Air India) send their aircraft to MROs operated by Boeing/ Airbus company at off-shore locations like Dubai, Singapore, etc (GIDB, 2020).

As data on annual purchase quantity was only available, amount of used oil generated by each organisations was estimated using the empirical formula explained at section 4.6.1 of previous chapter. Airline wise results of the estimates are shown in table 5.5.

5.3.3 Estimating Volumes of Used Oil (Defence Sector Operators)

A scheduler as discussed in section 4.6.1 of previous chapter was distributed to Indian Air Force airports/ bases/ stations located in north India, where aircraft servicing facilities are available. According to the findings of the primary survey of maintenance practices, it was observed that the floor level operator/ supervisor of most defence facilities were not maintaining data on quantities of used oil discharges during servicing. Therefore, exact quantities were not readily known. The probable quantity of used oil collection was estimated using empirical formula explained at section 4.6.1 of previous chapter. The total operational losses have been valued at 35% of purchase quantity, and accounts for fair consumption, handling and transportation losses. The results of the finding for civil airlines and defence airbases are shown in table 5.5. All figures have been normalised due to security and commercial concerns of parent organisations.

CONSUMPTION AND DISPOSAL PATTERN: AVIATION OIL

Location	Purchase Qty (Normalised)		Oil Purchase (Annually)	Losses	Reclaimable Aviation Oil
	Eng Oil	Hyd Oil			
DEFENCE AIRBASES					
Adampur	22.25	22.25	44.51	15.58	**28.93**
Agra	40.75	40.75	81.51	28.53	**52.98**
Ambala	28.85	28.85	57.70	20.20	**37.51**
Bareilly	23.94	23.94	47.88	16.76	**31.12**
Bhatinda	10.18	10.18	20.35	7.12	**13.23**
Chandigarh	26.88	26.88	53.76	18.82	**34.94**
Delhi	3.09	3.09	6.18	2.16	**4.02**
Gwalior	25.53	25.53	51.07	17.87	**33.19**
Halwara	21.90	21.90	43.79	15.33	**28.46**
Hindon	9.99	9.99	19.99	7.00	**12.99**
Jodhpur	24.17	24.17	48.34	16.92	**31.42**
Leh	2.69	2.69	5.39	1.88	**3.50**
Pathankot	15.26	15.26	30.52	10.68	**19.84**
Sarsawa	9.80	9.80	19.59	6.86	**12.74**
Sirsa	16.80	16.80	33.60	11.76	**21.84**
Srinagar	12.51	12.51	25.01	8.75	**16.26**
Suratgarh	17.77	17.77	35.54	12.44	**23.10**
Udhampur	4.79	4.79	9.57	3.35	**6.22**
CIVIL AIRLINES					
AI Delhi	133.46	133.46	266.92	93.42	**173.50**
Indigo	260.41	260.41	520.83	182.29	**338.54**
Jet Airlines	288.97	288.97	577.93	202.28	**375.66**

Table 5.5: Estimated availability of used aviation oil for reclamation

5.3.4 Mapping System Volumes with Reclamation Facilities

Aircraft operations have a very wide geographical spread; they can be operated across continents. However, aircraft maintenance activities are base dependent and centered around large operational bases which have MRO facilities and sufficient infrastructure. The data acquired with the help of the scheduler distributed to various Indian Air Force bases and civil airlines was discussed in section 5.3 and table 5.5. Its clear from the table that high volumes of used oil are be available at only a few locations across the country. This information/ data was used to define the order and characteristics of the reverse supply chain for used oil. The data has also contributed in understanding the economic strategy and important positives for the reclamation industry. The list of locations in north India where high volumes of used aviation oil is generated was mapped with reference to table 5.5. The location of authorised oil reclamation facilities in the states of Punjab (PPCB, 2014), Haryana (HSPCB, 2014) and Uttar Pradesh (UPPCB, 2017) was matched with closest aircraft MRO (defence/ civil). Table 5.6 maps the location of aircraft MRO with closest reclamation centre. The distances are calculated using google maps.

Consequently, a map depicting the geographical location of MROs (Defence and Civil) where technical activities involving change of aviation oil take place is shown in figure 5.1 below. However, according to the MoEF&CG (Ministry of Environment, Forest and Climate Change), Hazardous Waste Management Rules of 2016, there are certain restrictions on the movement of used oil from one state to another. Therefore, the reclaimer from within the same state were selected as the destination for used aviation oil. The sates of Jammu & Kashmir and Himachal Pradesh were not considered for routing used oil due to the limited number of reclamation facilities in the states.

DISTANCE CHART: MAJOR MRO TO RECLAMATION CENTRES

Sl No	Location	Oil Availability	Nearest Reclaimer	Distance (Km)
1.	Adampur	28.93	Jalandhar	24
2.	Agra	52.98	Ghaziabad	208
3.	Ambala	37.51	Yamuna Nagar	60
4.	Bareilly	31.12	Pilibhit	51
5.	Bhatinda	13.23	Bhatinda	15
6.	Chandigarh	34.94	Yamuna Nagar	104
7.	Delhi/Palam	4.02	Delhi	15
8.	Gwalior	33.19	Gwalior	15
9.	Halwara	28.46	Ludhiana	32
10.	Hindon	12.99	Ghaziabad	10
11.	Jodhpur	31.42	Jodhpur	10
12.	Leh	3.50	Jalandhar	808
13.	Pathankot	19.84	Jalandhar	113
14.	Sarsawa	12.74	Meerut	181
15.	Sirsa	21.84	Bhatinda	98
16.	Srinagar	16.26	Jalandhar	442
17.	Suratgarh	23.10	Bathinda	151
18.	Udhampur	6.22	Jalandhar	242
19.	AI, Delhi	173.50	Delhi	15
20.	Indigo	338.54	-	-
21.	Jet Airlines	375.66		

Table 5.6: Used Aviation Oil quantity and Distance Chart

The location of various defence and civil MRO's in North India and the location of the closed oil reclamation facility is shown in the map below (Figure 5.1).

LOCATION MAP OF MRO & RECLAMATION CENTRES: NORTH SECTOR

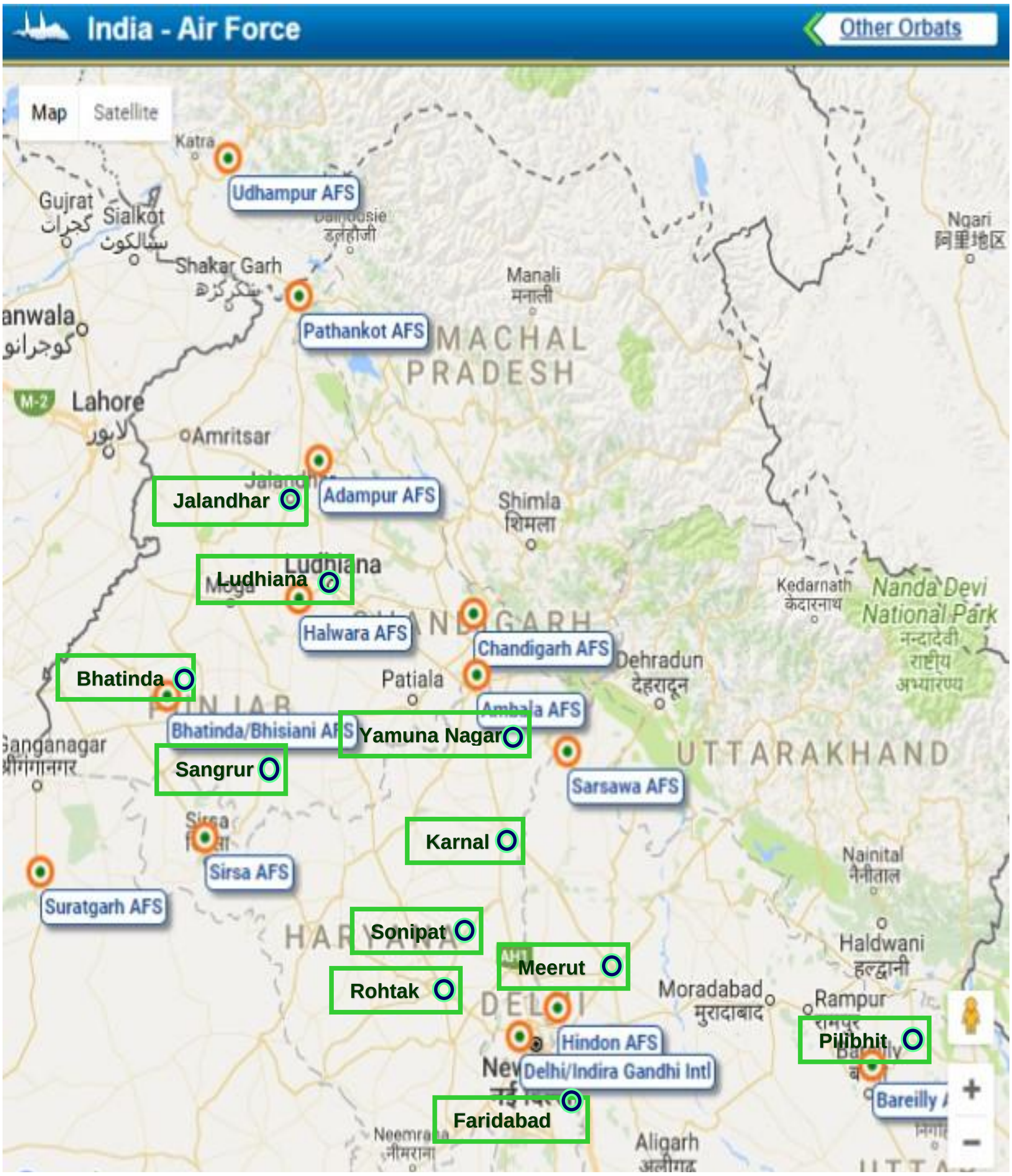

Figure 5.1: Map of Northern Sector Showing Location of MRO and Oil Reclaimer
Source: (Dutch Aviation Society / Scramble, 2020)

5.4 Objective II: Designing the RSC (Simulation using AHP)

According to the information collected during the market survey explained at section 5.2 above, it was evident that while the purchase of aviation oil is controlled, the process of collection and disposal of used oil is loosely regulated. The drained out used oil is collected in waste oil containers and sent as scrap to the warehouse. In most MRO's no formal accounting mechanism was in place to record the quantity and quality of used oil generated during aircraft servicing. However, the floor level supervisors agreed with the notional quantities of waste oil generation, estimated at table 5.4 above. This section evaluates and validates the inter-relationship between the key determinants of the reverse supply chain identified in Chapter 4 and optimises the results using Analytic Hierarchy Process (AHP).

The arrangement of various functionaries in aggregating, accounting and transporting used oil for reclamation is shown in the schematic diagram. The material flow for the supply chain of oil is also depicted in figure 5.2.

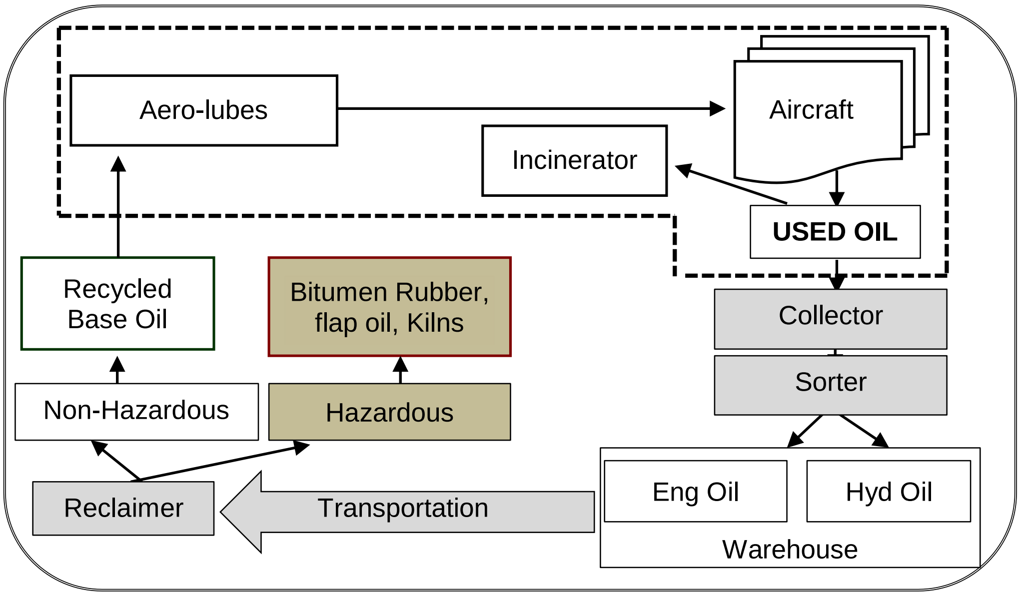

Figure 5.2: Relative position of functionaries in RSC of used oil

Standard advisories on aircraft maintenance practices, warrants technicians/ engineer to ensure a neat and clean work space. They are required to avoid spillage of oil or chemicals in and around the work area including aircraft operating area (DGCA Regulation). However, no literature (advisories) could be found explaining the collection and accounting mechanism for used oil drained during servicing. Same was confirmed during on-site interaction with operators, technicians, engineers, etc. It was also observed that within the maintenance setup, individuals were not directly responsible for the following activities, which could contribute directly towards the management of used oil.

A Collector: No individual was directly responsible for collection of used oil drained from the aircraft/ equipment. No documentation/ accounting methods were in place to record quantities of drained out oil from aircraft.

B Sorter: The oil drained from the aircraft was being moved to the store. All types and grades of used oil in workshop was being accounted a single inventory item code called waste oil. No sorting of oil by ‘type’ was carried out at the salvage store/ warehouse. All types and grades of oil were mixed together and stored in common drums/ containers.

C Transporter: All types of waste and used oil being received at the store was identified as a single item code. No specialised segregation and transportation mechanism was in use.

D Recovery: The recovery action by the storekeeper was limited to collecting the used oil and processing the case for ensuring speedy auctioning of the same. He was not responsible for kind of quality or quantity checks on the used oil being disposed to the scrap dealers.

Inventory managers of aviation stores also confirmed that all the oil is collected and stored under a single inventory code number. The entire stock of used oil of all makes and varieties is accounted for and also disposed-off as a single item. The used oil contains all types of oil drained from aircraft, ground air-conditioning vehicles, ground support vehicles, aircraft specialist vehicles, etc.

The results of the primary market survey and the responses from on-site supervisors as stated above, were factored while formulating the questionnaire for Analytical Hierarchy Process (AHP). The network design proposed at section 4.8 of chapter 4, was put-up for evaluation by domain experts. As discussed in section 4.9, the decision-making tool AHP was used for improving the post use management of aviation oil. A set of question were used to generate priorities from amongst a given set of alternatives, for arriving at a decision. The basic framework of questions, which represented the goal or objective and alternatives were also discussed in section 4.9.2. The questionnaire as discussed in section 4.10 was circulated to domain experts as hard copies/ personal interviews or sent using 'Google forms'. The responses received from experts is discussed in the next section.

5.4.1 Mapping Experts' Responses

In the first step, the experts were asked to weigh the nodes of the RSC with each other to suggest which of them would offer the greatest stimulus to the management's decision to change from incinerating oil to reclaiming used oil. Thereafter, the experts were also asked to assign weightage to various factors within each node that is likely to influence the quantity and quality of the oil collected for reclamation. The experts also considered factors like existing regulations, additional cost to the company, workers training levels and availability of matching infrastructure while expressing their opinions on the performance indicators suggested in the questionnaire.

Responses to the questions discussed in section 4.10, were received from 42 domain experts. There were twenty-six respondents from user agencies (Group I) and sixteen from regulator/ academic institutes (Group II). The geometric mean of the responses received from the individual respondents was calculated to obtain central value. This value was considered as weight for given choice and used in the AHP model for evaluation. The weightages assigned by the experts to the pairwise comparisons were inserted into the model. The details of responses received from individual domain experts is attached at **Appendix A6**. Consistency check was also carried out so as to ensure that the order of prioritisation assigned by the experts was in a logical sequence. 'Microsoft excel' matrix multiplication function '=MMULT( )' was used to compute the Consistency Measure, calculate Consistency Index (CI) and Consistency Ratio (CR). The tables 5.7.1 to 5.7.5 presents the weight assigned to each set of questions for respective pair-wise comparison matrix.

Q-1 Which factor amongst the following has the greatest influence on deciding the efficacy of RSC of used aviation oil.				
Factor	**Collection**	**Sorting**	**Transportation**	**Reclamation**
Col	1	1/4	1/8	1
Sort	4	1	1/3	3
Trans	8	3	1	6
Reclm	1	1/3	1/6	1

Table 5.7.1: Comparison Matrix – Efficiency of RSC

Q-2 Which factor amongst the following has the greatest influence on the Collection volumes of used aviation oil.				
Factor	**Regulation**	**Training**	**Specialized Tools**	**Disposal Instruction**
Reg	1	1/3	1/6	1/6
Train	3	1	1/2	1/4
Spl Tool	6	2	1	2
Disp	6	4	1/2	1

Table 5.7.2: Comparison Matrix – Collection in RSC

Q-3 Which factor amongst the following has the greatest influence on the Sorting of used aviation oil.			
Factor	**Regulations**	**Warehousing Efficiency**	**Inventory Carrying Cost**
Reg	1	1/6	1/3
W/H effy	6	1	1
Inv CC	3	1	1

Table 5.7.3: Comparison Matrix – Sorting in RSC

Q-4 Which factor amongst the following has the greatest influence on the Transportation of used aviation oil.		
Factor	**Transhipment Quantity**	**Transportation Distance**
Transhipment Quantity	1	5
Transportation Distance	1/5	1

Table 5.7.4: Comparison Matrix – Transportation in RSC

Q-5 Which factor amongst the following has the greatest influence on the Reclamation of used aviation oil.			
Factor	**Cost of Technology**	**Economy of Process**	**Regulations**
Technology	1	1/4	5
Economy	4	1	8
Regulations	1/5	1/8	1

Table 5.7.5: Comparison Matrix – Reclamation in RSC

The result of the AHP questionnaire was further computed using 'Microsoft excel'. The Priority vectors (criteria weight) for the normalized matrix, consistency index and consistency ratio was also computed and checked. The consistency ratio for all tables were found below, the threshold of 10% suggested by Prof Saaty. Therefore, the through-put of the survey were accepted. The results of the analysis are discussed in the next section.

5.4.2 Scenario Evaluation and Validation

The functional influence of each factor or criteria in the RSC is estimated by calculating the weighted average for each decision factor. The factor with the highest score/ overall ranking is considered as the best option. However, in this case, since two levels of decision is involved (refer section 4.9.2), the overall priority for each factor of level 3 is required to be computed in accordance with the weightage assigned to corresponding factor in level 2. To estimate this, AHP recommends combining the local priority weight of the factor with the comparative rating of the respective sub-factor. This combined weight of each factor is called Global Weight and computed using the following formula.

$$Global\ Weight = \sum (Local\ wt\ for\ f_i\ )\ X\ (Local\ wt\ for\ sub - factor\ f_j\ i.r.o\ \ (f_i))$$

Table 5.8 maps the priority vector of each factor calculated from inputs received from experts as shown in section 5.4.1 above and then computes its relative global weight using the formula discussed above.

GLOBAL RANKING

Primary Factor	Local Weight	Secondary Factor	Local Weight	Global Weight	Global Rank
Collection	0.073	Regulation	0.058	0.00423	**12**
		Training	0.157	0.01146	**10**
		Spl Tools	0.424	0.03095	**6**
		Disposal	0.361	0.02635	**7**
Consistency check for 'Collection'- CI= 0.062, RI= 0.9, for n=4, CR= 0.069					
Sorting	0.245	Regulation	0.107	0.02622	**8**
		Warehousing	0.497	0.12177	**2**
		Carrying Cost	0.397	0.09727	**4**
Consistency check for 'Sorting'- CI= 0.027, RI= 0.58, for n=3, CR= 0.046					
Transportation	0.597	Quantity	0.833	0.49730	**1**
		Distance	0.167	0.09970	**3**
Consistency check for 'Transportation'- CI= 0, RI= 0, for n=2, CR= N/A					
Reclamation	0.084	Technology	0.244	0.02050	**9**
		Economics	0.689	0.05788	**5**
		Regulation	0.067	0.00563	**11**
Consistency check for 'Reclaim'- CI= 0.047, RI= 0.58, for n=3, CR= 0.082					
Consistency check for Primary Factors - CI= 0.0104, RI= 0.90, for n=4, CR= 0.012					

Table 5.8: Computation of Global Rank of each factor

5.4.3 Interpretation of Result

The weightages assigned by the domain experts to various factors for the objective, 'Should used aviation oil be Incinerated or Recycled?' were analysed. The ranking allotted to each factor, reflects its order of influence on the decision to bring about qualitative changes. It is implicit that emphasis ono these factors would enable a transformation in approach by enhancing collection for 'incineration' rather than collection for 'reclamation'.

The hierarchy of the impact of the primary factors on post use management of aviation oil is tabulated below. Transportation appears to be the most important factor considered by the experts. The other factors in order of precedence were sorting (warehousing), reclamation (technology) and collection.

HIERARCHY OF IMPACT OF PRIMARY FACTOR

Extremely important	Transportation
Slightly important	Sorting
Moderately less important	Reclamation
Strongly less important	Collection

Table 5.8.1: Hierarchy of Primary factors

The performance of the primary factor also influences the relative position (weight) of secondary factors. Computing the effect of performance indicators within each node indicate their influence on the outcome of the optimization plan. According to the experts the most important sub-factor (performance indicator) within each primary factor is as tabulated below: -

PRIMARY FACTOR Vs PERFORMANCE INDICATORS

Factor	Performance Indicator
Transportation	Transit Quantity
Sorting	Warehouse efficiency
Reclamation	Economics of operation (process cost)
Collection	Availability of specialised tools for collecting used oil

Table 5.8.2: Performance Indicators for Primary Factor

The above tables, the following the inferences can be drawn: -

(a) Quantity of used oil available for transportation is the most important factor for the operationalisation of the reverse supply chain for used aviation oil.

(b) The warehousing requirements and sorting activities which ensure segregation of different types of oil is also an important factor in improving the efficiency of RSC.

(c) The proximity of the location of oil reclamation facility is an important criterion, as the transportation distance has been assigned 3rd rank in the priority list.

(d) Experts have assigned higher weightage to the economics of reclamation. This can be interpreted as; the cost of reclamation of used aviation oil would be an important factor, for choosing reclamation over incineration. Development of specialised technology for reclamation of used oil may also improve the economics of the RSC.

(e) Experts have opined that use of specialised tools and issuance of explicit disposal instructions can improve the collection of used aviation oil.

(f) Providing additional training to technicians on handling used oil may marginally improve collections.

(g) Framing regulations for collection is not the judged as an important factor for improving the RSC network. Effective implementation of existing rules may maximise collection.

(h) Similarly, no new regulations on reclamation and sorting is required to be formulated, enforcing existing provisions would improve the efficiency of the RSC. However, a method to record and audit the disposal of used oil may be introduced in the regulations.

5.5 Objective III: Developing the Transportation Plan

The results of AHP suggests that the quantity in transit and distance are the two most important factor in the RSC design for used. Therefore, aviation MRO's should focus on aggregating larger quantities of waste oil so that larger volumes can be sent for reclamation. Further, the oil reclamation facilities should be located as close to the MRO as feasible to reduce transportation cost.

For optimising the transportation plan for used aviation oil the following assumption have been made: -

(a) MROs were mapped to the nearest oil reclamation facility, as notified by the state government (Haryana State Pollution Control Board, 2017), for reducing the cost of transportation.

(b) Transportation cost was calculated for the normalised annual yield of each MRO to the nearest reclaimer as mapped in table 5.6.

(c) The per-ton-km cost for small open truck, used for transporting 1000 ltrs (density of oil is approximately 880kg/m^3) of used oil is assumed @ ₹ 50 per km-ton (truckbhai.com, 2020). The trip load is fixed for minimum 1000ltrs/ 880 kgs.

(d) The notional average trip expense shown in table 5.6 is for illustrative purpose only. The rates are fixed at per-tonne-km rate for north India. The maximum travel distance is below 500kms. The cost of transportation is borne by the seller.

(e) Aviation oil i.r.o. all civil airlines is assumed to be drained at Delhi MRO.

(f) Used oil is required to be transported from Leh to Jalandhar to reduce pollution at eco-sensitive regions.

The transportation plan for used aviation oil is shown below at table 5.9.1.

TRANSPORTATION COST: USED AVIATION OIL

Sl No	Location	Used Oil (100 kgs)	Nearest Reclaimer	Dist (Km)	No of Trips/ year	Transport Cost
1.	Adampur	28.93	Jalandhar	24	3	**3,600**
2.	Agra	52.98	Ghaziabad	208	5	**52,000**
3.	Ambala	37.51	Y/ Nagar	60	4	**12,000**
4.	Bareilly	31.12	Pilibhit	51	3	**7,650**
5.	Bhatinda	13.23	Bhatinda	15	1	**750**
6.	Chandigarh	34.94	Y/ Nagar	104	3	**15,600**
7.	AF, Palam	4.02	Delhi	15	1	**750**
8.	Gwalior	33.19	Gwalior	15	3	**2,250**
9.	Halwara	28.46	Ludhiana	32	3	**4,800**
10.	Hindon	12.99	Ghaziabad	10	1	**500**
11.	Jodhpur	31.42	Jodhpur	10	3	**1,500**
12.	Leh	3.5	Jalandhar	808	1	**40,400**
13.	Pathankot	19.84	Jalandhar	113	2	**11,300**
14.	Sarsawa	12.74	Meerut	181	1	**9,050**
15.	Sirsa	21.84	Bhatinda	98	2	**9,800**
16.	Srinagar	16.26	Jalandhar	442	2	**44,200**
17.	Suratgarh	23.1	Bathinda	151	2	**15,100**
18.	Udhampur	6.22	Jalandhar	242	1	**12,100**
19.	Civil Air, Dehi	887.7	Delhi	15	89	**66,750**

Table 5.9.1: Cost of Transportation of used oil to reclaimer

A detailed analysis of the transportation plan as modelled in the table shown above, bring out the following facts: -

(a) Except for MRO's at Leh, Srinagar and Udhampur, all others are within 200 kms of reclamation facilities.

(b) Interstate transport of used oil can be avoided, except for the Union Territories of J&K and Leh. Setting-up of oil reclaiming facilities in Srinagar area is recommended.

(c) The quantity of used oil disposed by each MRO is less than the installed capacity of each reclamation plant (Min of Environment, Forest & Climate Change, 2019). Therefore, it is commercially not justified to establish new dedicated facilities for reclaiming used aviation oil.

(d) Availability of too many reclaimer for the limited supply in the market kills incentive to invest in new technology for aviation oil. Therefore, it is necessary to limit the number of approved aviation oil reclaimer to one each in the states of Punjab, Rajasthan, Uttar Pradesh and Haryana. This will ensure fair competition as well as enable better capacity planning by companies. Reclaimer will also be assured of continuous supply of used oil. The formation of aviation oil clusters is suggested for better remuneration.

(e) Data on used oil generated by aviation industry is directly dependent on the flying effort of the airline. This information should be put-up in public domain, so that reclaimer can plan production/ reclamation efforts.

(f) Production planning and Bills of Material for additives/ catalysts required for processing used aviation oil is difficult to estimate/ procure at competitive price due to the non-availability of the correct estimates from aviation industry.

(g) The changes in notional earning due to better scheduling of capacity and availability will generate better remunerations. Thereby make the process financially sustainable.

(h) The collateral strategic gains to the country in terms of forex (import of base oil) and environment protection are not mapped in this study.

Revised transportation plan with reclamation clusters is shown in table 5.9.2.

CLUSTER WISE TRANSPORTATION PLAN

Sl No	Location of MRO	Nearest Reclaimer	Distance	Revised Tpt Cost	Earning to MRO	Earning to Reclaimer
1.	Leh	Jalandhar	808	40400	169600	**87500**
2.	Srinagar	Jalandhar	442	44200	931400	**406500**
3.	Udhampur	Jalandhar	242	12100	361100	**155500**
4.	Pathankot	Jalandhar	113	11300	1179100	**496000**
5.	Adampur	Jalandhar	24	3600	1732200	**723250**
6.	Halwara	Jalandhar	88	13200	1694400	**711500**
7.	Bhatinda	Jalandhar	170	8500	785300	**330750**
	Total for **Punjab Cluster**			Available Oil= 116.44		**2911000**
8.	Sirsa	Rohtak	200	20000	1290400	**546000**
9.	Ambala	Rohtak	199	39800	2210800	**937750**
10.	Chandigarh	Rohtak	241	36150	2060250	**873500**
	Total for **Haryana Cluster**			Available Oil= 94.29		**2357250**
11.	Agra	Meerut	244	61000	3117800	**1324500**
12.	Bareilly	Meerut	212	31800	1835400	**778000**
13.	Hindon	Meerut	60	3000	776400	**324750**
14.	Sarsawa	Meerut	151	7550	756850	**318500**
15.	Civil Air Delhi	Meerut	95	422750	52839250	**22192500**
16.	AF Palam	Meerut	95	4750	236450	**100500**
17.	Gwalior	Meerut	376	56400	1935000	**829750**
	Total for **UP Cluster**			Available Oil= 1034.74		**25868500**
18.	Jodhpur	Jodhpur	10	1500	1883700	**785500**
19.	Suratgarh	Jodhpur	432	43200	1342800	**577500**
	Total for **Rajasthan Cluster**			Available Oil= 54.52		**1363000**

Table 5.9.2: Revised Transportation Plan and Cost Benefit

P.S.

Notional earning to MRO has been is estimated @ ₹ 60/-per litre oil, minus cost of transportation.

Notional earning for reclaimer is estimated @ ₹ 25/.

5.6 Conclusion

The findings of the preliminary market survey and analysis of data available in the open domain was discussed. It was evident for the initial observations that post use management of aviation oil was not very well organised and documented. Used aviation oil was not being considered as a recyclable, reusable polluting product in India. This was contrary to global practices on management of used oils.

Detailed survey in the form of interview and online questionnaire was conducted to investigate the reasons for wasteful disposal of aviation oils. Domain experts from oil industry, aviation industry, academic and research institute were also asked to opine on the methods to improve the management of used oil. A reverse supply chain network was designed in-line with those for reusable polluting products. This network was optimised using AHP technique.

According to the results of the process, transportation of used oil appeared to be the main factor for the proposed network. Accordingly, the essential elements of transportation vis-à-vis, quantity in transit and distance between MRO and reclamation facility were fine-tuned to get the best results. The results of the transportation plan were discussed in the previous section. Realigning the transportation plan will bring in financial gains to both the airline industry as well as the oil reclaimer.

The related work on the subject carried out by the author and recommendations for future work are discussed in the next chapter.

CHAPTER 6

RECOMMENDATIONS AND CONCLUSION

6.1 Conclusion

While a lot of exploratory and analytical research has been carried out in the domain of forward supply chain, limited work has been conducted on reverse supply chains, especially those connected with commercially re-usable products. The renewed attention to environmental issues has given rise to green Supply Chains (SC), however most of these green SC models are develop for optimizing the movement of the fresh stores. There is an exceedingly large research space for exploring green chains for reusable, reclaimable and recyclable products in India. The commercial space for such products can be exploited profitably by developing an enabling ecosystem centered around technology and functional supply chains mechanism.

The primary goal of this thesis was to design, develop and optimize a Reverse Supply Chain (RSC) model for used aviation oil in India. The RSC presented in this thesis has been developed over the existing models for polluting products, which have completed their useful life, by considering used aviation as an 'End-of-Life' Returnable/ reusable product. After factoring all variables associated with the aviation sector, oil industry and environmental norms, the RSC was optimized to achieve not only reduction in pollution but also considerable financial gains for all stakeholders.

The key takeaways of this thesis are enumerated below: -

(a) Over 66% of India's requirement for petroleum based lubricating oils used in transportation sector, manufacturing industry, power sector, etc, is met by imports. While those used directed in aircraft are almost entirely imported. India imported lubricants worth over ₹ 9,500Cr in year 2018.

(b) Indian aviation industry, including defense aviation consumes over 11 lakh liters of aero-lubes (Aviation oil) annually.

(c) Reclaiming used oil is a globally establish policy, with most environmentally conscious countries recycling over 40%-60% of used oils. India is yet to achieve/ set measurable targets for used oil reclamation. This is in-spite of Government's regulatory directions in place since year 2016.

(d) Primary market survey presented, careless disposal and low collection volumes for used oil due to absence of,

(i) Awareness amongst users and technicians about technologies to reclaim used oil.

(ii) Established system for collection and disposal of used oil.

(e) Market survey and technical evaluation also suggested reclamation of used aviation oil is at least three times more profitable than incineration.

(f) Response received from aviation sector users and supply chain domain experts brought out that the following deterministic factors or variable that influence the value chain of used aviation oil: -

<u>Intrinsic Factors</u>

(i) Collection/ handling cost

(ii) Sorting/ Inventory management cost.

<u>External Factors</u>

(i) Transportation cost

(ii) Reclamation Technology

(iii) Taxation/ regulatory policies

(g) Accordingly, the four major factors influencing the RSC operations of used aviation oil were identified as **Collection**, **Sorting**, **Transportation** and **Reclamation**. These were designated as decision criterion or nodes.

(h) Alternate factors for each of the above nodes were identified with the help of domain experts including academicians. The same is tabulated below: -

CRITERIA (Objective)	**ALTERNATE FACTOR**
Collection (Maximise collection at minimum cost)	Introduce regulatory mechanism
	Use of specialised tools
	Enact training and skilling program
	Motivation to reduce unsolicited disposal
Sorting (Reduce segregation and handling cost)	Inventory handling cost
	Storage policies
	Warehousing effectiveness cost
Transportation (Maximum quantity at minimum cost)	Transit Cost
	Transit Quantity
Reclamation (Maximise recovery at minimum environmental cost)	Economy of Efforts
	Regulation on disposal of waste
	Availability of Environmentally Safe Technology

(i) Thereafter, a model representing the relationship between all stakeholders including, user, collector, storekeeper, reclaimer, transporter, regulators, etc was drawn-up. These connections were integrated into a single networked chain with finite and measurable influencing factors for the purpose of optimisation.

(j) The level of influence of each factor was evaluated using AHP. The result of the assessment process is listed below: -

- ✓ Cost of Transportation is influenced by quantity and distance.
- ✓ Cost of warehousing is proportionate with quantity in store/ transit.
- ✓ Cost of reclamation governed by the efficiency of technology to produce new usable product.
- ✓ Handling cost and taxation are dictated by regulation on transboundary (inter-state) movement of used oil.

(k) The summary of the effects and reasoning i.r.o. all the deterministic factor for the RSC model is tabulated below: -

VARIABLES AND THEIR EFFECT ON RSC MODEL

<table>
<tr><th>Sl No</th><th>Factor</th><th>Effect</th><th>Justification from AHP analysis</th></tr>
<tr><td colspan="4">Intrinsic</td></tr>
<tr><td>1</td><td>Collection</td><td>Negligible</td><td rowspan="2"><u>Difference Between</u>
Collection & sorting for <u>incineration</u> Vs collection & sorting for <u>reclamation</u>
• Negligible change in manning efforts
• No appreciable additional investment in tools, equipment and infrastructure
• Significant financial gains by reclaiming used aviation oil</td></tr>
<tr><td>2</td><td>Sorting</td><td>Negligible</td></tr>
<tr><td colspan="4">External</td></tr>
<tr><td>3</td><td>Transportation</td><td>Strong</td><td>Re-routing according to quantities in transit</td></tr>
<tr><td>4</td><td>Technology</td><td>Moderate</td><td>May require improvement</td></tr>
<tr><td>5</td><td>Regulation</td><td>Mildly</td><td>Introduction of internal audit system</td></tr>
</table>

Table 6.1: Factors influencing RSC of used oil

(l) Transportation cost and quantity in transit appear to be the most significant factors in defining the sustainability and profitability of the RSC for used aviation oil.

(m) The transportation model for each location was also worked out separately. One dedicated oil reclaimer in each state is sufficient to meet the existing market size of used aviation oil.

(n) The RSC model for used aviation oil can be used for developing aggregating ecosystems for other similar product. Collection and re-processing of many polluting products like used tyres, used batteries, auto-parts, etc can be made more profitable by re-modelling their supply chains.

6.2 **Recommendations**

Detailed analysis of the workflow, enabling commercial ecosystem and policies on the subject, had brought forth certain limitations towards development of a sustainable ecosystem. The following action points are recommended.

At regulatory level, the following amendments are recommended to the existing Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (MoEF&CG, GoI, 2016). These changes may force aviation organisations to improve the management of used lubricants: -

(a) Free movement of used aviation oil from one state to other without additional taxation and NoC, should be permitted.

(b) User organisation (MRO) should submit complete procurement figures of oil inventory alongwith oil consumption data. Quantities of used oil disposed should be audited periodically by respective state pollution control boards.

Indigenous development and production of aviation lubricants requires an impetus from the Ministry of Civil Aviation and Ministry of Petroleum and Natural Gas in terms of assured demands from airlines and funding for Research & Development. According to the Bureau of Indian Standards' sectional committee on lubricants, there are over 28 major lubricant manufacturers in India (BIS Technical Committee, 2018). Their products are sold under various brand names like SERVO, Castrol, Mobil, Elf TOTAL, etc. These companies are engaged in the manufacture, blending and marketing of different types of lubrication oils used in automobile, manufacturing industry, transformers, etc. However, none of these companies' manufacture aviation grade oil. Dis-interest amongst lubricant developer and manufacturers to venture into aviation sector was due to lack of support from Indian aviation sector to experiment with domestic products.

Increased focus towards developing commercially viable and environmentally safe technologies for reclaiming used aviation oil. There are over 250 oil reclaimer in India, they have developed technologies to reprocess, recycle, re-refine and reclaim almost all types of use oil. The Department of Science and Technology, Indian research labs have also developed suitable environmentally safe technologies to recycle used lubricants (Department of Science and Technology, 2015). Government owned oil companies had also committed to the Ministry of Petroleum and Natural Gas to reduce import of base oil by 25% by year 2023, by re-refining used base oil (The Hindu, 2018). However, there is a need to consider developing new reclamation technology for used aviation oil.

Lubrication oil sale, consumption and disposal data is not being consolidated at state or national level. Aero-lubes and automobile lubes are being treated as consumable inventory. As per nation guidelines used oil is considered as an industrial effluent. Its post use management is limited to safe disposal. The focus of regulators has not been on maximising collection for re-cycle/ re-use. Similarly, the Petroleum Conservation Regulatory Authority (PCRA), the national body on petroleum conservation has also not been mandated with conserving lubricants.

It is therefore proposed to set an organisation for auditing the consumption and post use management of lubricants. The audit body may be placed under PCRA (Petroleum Conservation Research Association) to systematically check the conservation of lubricants and oil. It may be named as Bureau of Oil Efficiency to regulate, manage and monitor the life cycle of lubes. Its role can be similar to the Bureau of Energy Efficiency (Bureau of Energy Efficiency, 2017) which functions under the Ministry of Power and audits the energy efficiency of all organisations and equipment. The bureau can also audit large public sector organisations like Railways, State Road Transport Undertaking, Public sector mining companies, Defence establishment, etc on their post-use oil management and disposal philosophy.

6.3 Proposals for Future Research Work

In year 2019, the Indian Air Force conceived an ambitious plan to develop indigenous technology for reclamation of used aviation grade hydraulic oil. The Ministry of Defence earmarked over rupees one crores for this project. According to the tender notice published on the ePublish website of the government of India on 09 Dec 2019 (Dte of Indg, IAF, 2019), technical proposals had been invited shortlisted research institutes and industries. It is estimated the technology would usher in a saving in terms of import of atleast 4 lakh ltrs of aviation grade base oil by India. Further, Techno-logistics studies need to be carried out to assess the feasibility of using this technology to reclaim aviation oil with reduced logistics. Contract for development of commercially sustainable technology has been awarded by IAF in Jul 2020 to an Indian firm. There is a possibility to develop sector specific technologies for large consumers like Indian Railways, Shipping Industry, etc.

M/s Avi-Oil India (P) Ltd, a government owned enterprise is the only Indian oil manufacturer for aviation oil. The company's clientele includes Indian defence forces and few small commercial aviation companies. Majority of commercial airlines import their entire stock of lubricant (Shrivastava, 2020) from companies located in south east Asia. According to the experts from the Oil Technologists Association of India (OTAI), base oil required for the manufacture of high quality lubricants is not available in India. There is a need to develop technologies to improve the quality of domestic aero-lubes so that they meet the international oil quality norms.

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Appendix A1

SCHEDULER FOR IAF RESPONDENTS

USAGE AND DISPOSAL OF AVIATION OILS: OPERATIONAL STATION

1 Lubricating oils are amongst the most expensive distillates of crude. The 'base stock' raw lubrication oil obtained from refinery has to be blended with other additives to attain the desired physical/ chemical properties for required application.

2 The consumption of Lubrication oils in India has grown steadily since 2005. Presently, we are the **fifth largest** lubricant market globally in terms of volume. In the year 2015-16, we consumed about 3.2 MMT (Million Metric Tons) of lubes of this only 1 MMT of lubrication oil was indigenously produced, which means 68.75% was imported. These figures highlight our increased dependency on foreign vendors to supply lubricants which are essential to support growth. During the same period IAF purchased over 6.8 lakhs litres of Lubs at about Rs Nine crores.

3 A study to map the consumption and post use management of aviation oils is being undertaken at this Center. In this regard you are requested to kindly offer comments/ opinion/ information w.r.t. the following questions. The questionnaire solicits data on consumption pattern and method of accounting of used/ downgraded aviation oil. Information pertaining to units under station AOR is requested.

Questionnaire:

Station/ Location : ______________(eg 12 Wg, AF/ Chandigarh)

Type of Aircraft/ Fleets :_____________.(eg IL-76/ Mi-26,/ Tpt/ Ftr/ Hptr)

A List the annual quantities of aviation oils (FH-51, Turbonycoil 210A, OX 27, etc) procured for the station through various sources, as per the following table:

Sl No	Type of Oil (Nomenclature)	Aircraft / Fleet	Consumption 2015-16		Consumption 2016-17	
			ED Supply (Ltrs)	Local Purchase (Ltrs)	ED Supply (Ltrs)	Local Purchase (Ltrs)
Eg	FH-51	IL-76	4000	1000	3000	500
	OX 27	Mi 26	200	40	500	-

B As per the recommendations of the maintenance manuals (OEM publication, SI/ TSI/ TO, etc) what is the consumption rate in % terms for each type of lubrication oil? Please list fleet-wise.

Type of Oil (Nomenclature)	Fleet	OEM recommendation	Actual/ achievable
Eg Turbonycoil 210A	IL 76	3-8%	5%

C List the annual quantities of waste aviation oil disposed-off by the station alongwith auction rate? Please do not include MT oils and fuel.

Sl No	**Type of Oil (Nomenclature)**	**2015-16**		**2016-17**	
		Quantity	**Rate**	**Quantity**	**Rate**

D Choose the accounting method for the used/ contaminated/ downgraded/ life expired aviation oil?

(a) Brought on Charge on IMMOLS as waste oil.

(b) Any other method. (Please state)………………

E Choose the method of disposal of used aviation oil

(a) By auction through MSTC.

(b) By burning in incinerators

(c) Any other method. (Pl state) ……………….

F What is the disposal method for the empty packing/ transportation cases/ containers of aviation oil?

(a) Destroyed by burning, etc

(b) Defaced and sold as scrap

(c) Returned to supplier

(d) Returned to ASC

(e) Any other method: - (Please enumerate)

Responses prepared by:

Appendix A2

SCHEDULER FOR CIVIL AVIATION

PROCUREMENT OF AEROLUBES: AIR INDIA

1 A study to compare the consumption pattern and cost of aviation oils across various organization is being undertaken at this Center. The aim of the study is to reduce the expenditure on aero-lubes by Indian Air Force without compromising operational efficiency. In this regard you are requested to kindly forward the following information w.r.t. Aerolubes (aircraft lubricating oils, excluding fuel).

2 It is acknowledged that this data is being collected for academic and research purpose only and the results would not be quoted/ used for any commercial purpose.

Questionnaire:

Please provide data on the quantities of aircraft lubricants (Hydraulic Oil and Engine oil only) procured annually by the company along with its contract rate. Please include quantities procured from all sources during the stated financial year.

Name of Operator (Organisation):_________________________

Sl No	Type of Oil (Nomenclature)	2015-16 (Hrs flown:.)			2016-17 (Hrs flown:.)		
		Quantity purchased	Supply Agency #	Contract Rate	Quantity purchased	Supply Agency#	Contract Rate
	Eg MJO II						
	Eg Skydol						

Example IOC/ OEM/ Indian vendor/ Foreign vendor

Wg Cdr A Shrivastava,

Center for Air Power Studies
Subroto Park, New Delhi

(M) 9650030808, Email: asheesh1470@gmail.com

Appendix A3

List of Domain Experts: RSC Aviation Oil

Sl No	Name	Appointment	Organisation
1	Air Cmde Pandey	Principal Director, Dte Maint Plans	IAF
2	Air Cmde	Principal Director, Dte Ops Lgs	IAF
3	Air Cmde	Principal Director, Dte of Store	IAF
4	Gp Capt	Dir, Dte of Maint Plan	IAF
5	Gp Capt	Dir, Dte of Engg Western Transport	IAF
6	Gp Capt	Dir, Dte of Engg Russian	IAF
7	Gp Capt	Dir, Dte of Engg Russian Fighter	IAF
8	Gp Capt	Chief Engg Officer, Srinagar	IAF
9	Gp Capt	Chief Engg Officer, Udhampur	IAF
10	Gp Capt	Chief Engg Officer, Pathankot	IAF
11	Gp Capt	Chief Engg Officer, Adampur	IAF
12	Gp Capt	Chief Engg Officer, Halwara	IAF
13	Gp Capt	Chief Engg Officer, Chandigarh	IAF
14	Gp Capt	Chief Engg Officer, Ambala	IAF
15	Gp Capt	Chief Engg Officer, Bhatinda	IAF
16	Gp Capt	Chief Engg Officer, Sarsawa	IAF
17	Gp Capt	Chief Engg Officer, Sirsa	IAF
18	Gp Capt	Chief Engg Officer, Suratgarh	IAF
19	Gp Capt	Chief Engg Officer, Hindon	IAF
20	Gp Capt	Chief Engg Officer, Bareily	IAF
21	Gp Capt	Chief Engg Officer, Agra	IAF
22	Gp Capt	Chief Engg Officer, Gwalior	IAF
23	Gp Capt	GM (Maint), Air India, Delhi	Air India
24	Gp Capt	GM (Maint), Indigo, Gurgoan	Indigo
25	Uday K Naidu	CEO, GMR Aero Technic Ltd	GMR Aero Technic Ltd
26	PK Sarangapani	Sr Instructor, Airbus Trg center	Airbus Gp India
27	Lt Genral	Dir Gen POL, ASC, Army HQ	Indian Army
28	Col K Rawat	Dir Supply & Transport, Army HQ	Indian Army
29	BK Sharma	Mr BK Sharma, Div Head, WMD-II	CPCB, Mo
30	P.K. Selvi	Ms PK Selvi, Sc D, WMD-II, MoE&F	CPCB
31	Alok Tripathi	Executive Director, PCRA	PCRA
32	Surender Pratap	Dir, R&D, PCRA	PCRA
33	Ashutosh Jindal	Jt Sec, MoP&NG	MoP&NG
34	KP Shrivastava	DDG, DGCA	DGCA
35	MS Sekhon	Dy Dir AW, DGCA	DGCA
36	SR Singh	Dir AW, DGCA	DGCA
37	PK Srivastava	D Stat, DGCA	DGCA
38	Narender Singh	Dy Dir (Stat), DGCA	DGCA
39	SK Singh	Dir Aircraft Engg, DGCA	DGCA
40	R R Kulkarni	Chief Manager (Technical Services), IOCL	IOCL, Mumbai
41	AK Jain	Chief Scientist, CSIR-IIP	CSIR-IIP
42	Rahul Raut	Professor, Operation & SC, NITIE	NITIE, Mumbai

Appendix A4

QUESTIONS TO DOMAIN EXPERTS

MANAGEMENT OF USED AVIATION OILS: EXPERT OPINION

1 The consumption of Lubrication oils in India has grown steadily since the last decade. Presently, India is the fifth largest lubricant market globally in terms of volume. During, 2015-16, our nation consumed about 3.2 MMT (Million Metric Tons) of lubes of this only 1 MMT of lubrication oil was indigenously produced, which means 68.75% was imported[1]. These figures highlight our increased dependency on foreign vendors to supply lubricants which are essential to support industrialisation and growth.

2. Reclamation and recycling of used oil is an accepted technology in industry worldwide. European and American nations use recycled oil as base oil to meet at least 40% of its domestic oil requirement. For example, 'British Columbia' recycles approximately 74.6% of its oil and Germany re-collects over 94% of used oil with 41% being reclaimed as fresh base-stock[2]. This is achieved through improvement in technology, firm regulations, user awareness and a robust reverse supply chain.

3. Primary survey of existing practices and data collected from Indian aviation sector suggests that only a small fraction of used oil drained from the aircraft is being returned to store and sold to reclaimers. Theoretically, larger quantities of used oil could be returned for reclamation, if it is managed properly. The key factors/ criteria which can help maximize/ improve the quantity/ quality of used oil are: collection, sorting, transportation and reclamation. This survey is aimed to identify the weightage of various factors/ criteria which will help optimize the reverse supply chain for reclamation of used aviation oil.

4. It is requested that you may kindly offer your valuable comments and assign weightages to choices enlisted under each alternative for questions Q1 to Q5. **For example, if you consider choice B as more important reason than choice A, for the given alternative, then assign 9 to choice B. Mark with a cross 'X' on the sliding scale.** A schematic diagram of the weighed scale is as shown below:-

Choice A	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		Choice B
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**							**X**	

5. It is acknowledged that this research survey is being carried out by under the aegis of University of Petroleum & Energy Studies, Dehradun, to study the post use management of aviation oils. The survey is only for academic and research purpose and the results would not be quoted/ used for any commercial purpose.

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[1] Ready Reckoner Snapshot of India's Oil & Gas data, Petroleum Planning & Analysis Cell (Ministry of Petroleum & Natural Gas), Jul 2016

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HIERARCHY FRAMEWORK FOR REVERSE SUPPLY CHAIN: USED AVIATION OIL DECISION LAYERS

Goal	Criteria	Alternatives
Optimize the Supply Chain **Should USED aviation oil be Recycled or Incinerated?**	**Collection**	Regulation/ Directives/ Policies
		Training of workers
		Use of Specialised Tools & shipping containers
		Unsolicited use/ Disposal
Objective: -Maximize Collection of used oil by minimizing unsolicited waste -Leverage potential of waste oil by capitalising on re-generation	**Sorting**	Regulation/ Directives/ Policies
		Warehousing Effectiveness
		Inventory Carrying Cost
	Transportation	Transit Quantity
		Transit Cost
	Reclamation	Availability of Environmentally Safe Technology
		Economy of Effort/ scale
		Regulation on disposal of waste

Q-1. **<u>Optimizing the Supply Chain</u>**: The supply chain for reclamation of used oil drained out from aircraft originates from the Tarmac/ Hangar/ Shop floor/ MRO/ etc where technical activities on oil system are carried out and ends at the reclamation plant. The quantity and quality of used oil collected and sent to store/ recycler is dependent on various factors including personal carrying out these activities. Inputs received from users/ operators suggest that the following criteria affects the supply chain.

(a) **<u>Collection</u>**. The scope of this criteria encompasses all technical activities (and technicians) involved in the process of collection of used oil drained from the aircraft during repair/ servicing. The quantity and quality of used oil collected from the repair site depends on the involvement and understanding of the technicians.

(b) **<u>Sorting</u>**. Sorting is the process of segregating different types of used oil so that it is not contaminated with other types of oil during transportation and storage. Sorting includes all activities and issues like regulations, warehousing, inventory management, etc that may affect the purity of collected oil and its unsolicited disposal. Proper sorting leads to better remunerations for the product.

(c) **<u>Transportation</u>**. This criterion includes all activities that affect the process of physical transportation of used oil from the service station to the store/ reclamation plant. Correct transportation policy can not only prevent wastage, reduce handling losses, reduce transportation cost and prevent further contamination of used oil.

(d) **<u>Reclamation</u>**. Recovery of used oil is technology driven and governed by many regulations including concerns for clean environmental. Reclamation reduces waste generation, reduces pollution and increases life of product. It also generates additional revenue for the exchequer.

The objective of the questionnaire is to evaluate the reason out '**Should USED aviation oil be Recycled or Incinerated?**'

From economic and environmental consideration reclamation supply chain should be optimized to ensure that maximum quantity of used oil reaches the recyclers/ reclaimers. Therefore, the objectives of the supply chain of used oil can be listed as follows: -

(a) Maximizing collection

(b) Reducing waste

(c) Preventing contamination and

(d) Reducing cost of transportation

In your opinion, which criteria amongst the set of alternatives stated below, have greater influence on the supply chain of used oil, for its journey from aircraft to reclamation plant? **Mark with a cross ‘X’ on the sliding scale.**

Set 1

Collection	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Sorting**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 2

Collection	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Transportation**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 3

Collection	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Reclamation**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 4

Sorting	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Transportation**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 5

<table>
<tr><td rowspan="3">Sorting</td><td colspan="2">Extremely important</td><td colspan="2">Strongly important</td><td colspan="2">Moderately important</td><td colspan="2">Slightly important</td><td>Equally important</td><td colspan="2">Slightly more important</td><td colspan="2">Moderately more important</td><td colspan="2">Strongly more important</td><td colspan="2">Extremely more important</td><td rowspan="3">Reclamation</td></tr>
<tr><td>1/9</td><td>1/8</td><td>1/7</td><td>1/6</td><td>1/5</td><td>1/4</td><td>1/3</td><td>1/2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td colspan="8">Factor A ←</td><td></td><td colspan="8">Factor B →</td></tr>
</table>

Set 6

<table>
<tr><td rowspan="3">Transportation</td><td colspan="2">Extremely important</td><td colspan="2">Strongly important</td><td colspan="2">Moderately important</td><td colspan="2">Slightly important</td><td>Equally important</td><td colspan="2">Slightly more important</td><td colspan="2">Moderately more important</td><td colspan="2">Strongly more important</td><td colspan="2">Extremely more important</td><td rowspan="3">Reclamation</td></tr>
<tr><td>1/9</td><td>1/8</td><td>1/7</td><td>1/6</td><td>1/5</td><td>1/4</td><td>1/3</td><td>1/2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td colspan="8">Factor A ←</td><td></td><td colspan="8">Factor B →</td></tr>
</table>

Q-2 The quantity of used oil collected from the work-station/ repair site may be affected by various factors. According to inputs received from servicing staff and shop floor management the volume of oil returned to store may be influenced by the following factors: -

(a) Absence of specific **Regulations**/ directives/ policies on accounting of each variety of used oil drained from aircraft as different inventory

(b) Lack of **training** of technicians and storekeepers working on/ supervising the repair activity on safe handling of used oil

(c) Non-availability of **specialized tools** and shipping containers for draining and transporting the used oil improve the quantity of collection, by minimizing wastage, spillage and handling efforts

(d) Lack of explicit instruction on preventing disposal/ **unsolicited use** of used oil within the workshop/ organization like using it for antirust painting, lubricating tools and equipment, as cleaning agent, etc.

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on the collection of used oil recovered/ drained from aircraft and thereafter returned to store? **Mark with a cross 'X' on the sliding scale.**

Set 1

Regulation	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Training**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 2

Regulation	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Specialized tools**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 3

Regulation	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		Unsolicited use
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 4

Training	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		Specialized tools
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 5

Training	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		Unsolicited use
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 6

Specialized tools	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		Unsolicited use
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Q-3 The **sorting** process affects the quality of used oil returned to reclaimer as contamination by other types of oil/ fuel/ water/ grease/ etc may result in lower recovery rates. According to experts from reclamation sector, proper sorting can not only improve the recovery rate but also reduce carbon footprint. Few factors which may influence the sorting process are listed below: -

(a) **Regulations**/ directives/ policies on inventory management of used oil drained from aircraft.

(b) **Warehousing** effectiveness - which is defined as the material handling capability and warehousing strategy of a store.

(c) Inventory **Carrying Cost** - which includes all expense towards the management of inventory in storage.

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on the Sorting process of used oil stored at the warehouse before being transported for reclamation? **Mark with a cross 'X' on the sliding scale.**

Set 1

Regulation	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Warehousing**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 2

Regulation	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Carrying cost**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 3

Warehousing	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Carrying cost**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Q-4 The efficiency of **transportation** criteria discussed in Q-1 above will significantly influence the supply chain. According to literature review, the following factors may affect transportation: -

(a) **Transit Quantity**.

(b) **Transit Distance**

In your opinion, which factor amongst the set of alternatives is likely to have greater influence on **transportation** component of reverse supply chain of used oil? **Mark with a cross 'X' on the sliding scale.**

<u>Set 1</u>

Transit Quality	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Transit Distance**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Q-5 The **Reclamation** criteria discussed above is technology driven and governed by many regulations including concerns for clean environmental. According to environment experts the following reasons influence the reclamation process: -

(a) Availability of environmentally safe **technology** in the industry for reclamation of used aviation oil

(b) **Economy** of effort and scale - strategic to employ minimum resources to obtain maximum output in commercial terms

(c) **Regulation** on disposal of waste (Hazardous and Other Wastes Rules, 2016).

In your opinion, which factor amongst the set of alternatives will have greater influence on the policy makers/ manager of aviation sector towards enforcing accounting/ collection of used oil for reclamation? **Mark with a cross 'X' on the sliding scale.**

<u>Set 1</u>

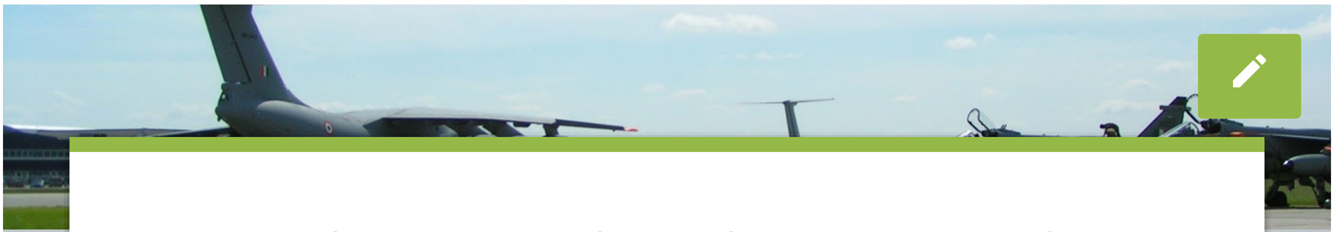
Technology	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Economy**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	← Factor A									**Factor B →**								

Set 2

Technology	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Regulation**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								

Set 3

Economy	Extremely important		Strongly important		Moderately important		Slightly important		Equally important	Slightly more important		Moderately more important		Strongly more important		Extremely more important		**Regulation**
	1/9	**1/8**	**1/7**	**1/6**	**1/5**	**1/4**	**1/3**	**1/2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	Factor A ←									**Factor B** →								



MANAGEMENT OF USED AVIATION OILS: EXPERT OPINION

1. The consumption of Lubrication oils in India has grown steadily since the last decade. Presently, India is the fifth largest lubricant market globally in terms of volume. During, 2015-16, our nation consumed about 3.2 MMT (Million Metric Tons) of lubes of this only 1 MMT of lubrication oil was indigenous, which means 68.75% was imported . These figures highlight our increased dependency on foreign vendors to supply lubricants which are essential to support industrialization and growth.
2. Reclamation and recycling of used oil is an accepted technology in industry worldwide. European and American nations use recycled oil as base oil to meet at least 40% of its domestic oil requirement. For example, 'British Columbia' recycles approximately 74.6% of its oil and Germany re-collects over 94% of used oil with 41% being reclaimed as fresh base-stock. This is achieved through improvement in technology, firm regulations, user awareness and a robust reverse supply chain.
3. Primary survey of existing practices and data collected from Indian aviation sector suggests that only a small fraction of used oil drained from the aircraft is being returned to store and sold to reclaimers. Theoretically, larger quantities of used oil could be returned for reclamation if it is managed properly. The key factors/ criteria which can help maximize/ improve the quantity/ quality of used oil are: collection, sorting, transportation and reclamation. This survey is aimed to identify the importance of various factors/ criteria which will help optimize the reverse supply chain for reclamation of used aviation oil in India.
4. Request kindly offer your valuable comments and assign numerical grades to choices enlisted under each alternative for questions Q1 to Q5. For example, if you consider the first choice as more important reason than second choice for the given comparison then select button under column 'extremely important'.
5. It is acknowledged that this research survey is being carried out under the aegis of University of Petroleum & Energy Studies, Dehradun, to study the post use management of aviation oils. The survey is for academic and research purpose only and the results would not be quoted/ used for any commercial purpose.

*Required

Email address *

Your email address

Optimizing the Reverse Supply Chain

The supply chain for reclamation of used oil drained out from aircraft originates from the Tarmac/ Hangar/ Shop floor/ MRO/ etc where technical activities on oil system are carried out and ends at the reclamation plant. The quantity and quality of used oil collected and sent to store/ recycler is dependent on various factors including personal carrying out these

activities. Inputs received from users/ operators suggest that the following factors affects the supply chain.
(a) Collection. The scope of this criteria encompasses all technical activities (and technicians) involved in the process of collection of used oil drained from the aircraft during repair/ servicing. The quantity and quality of used oil collected from the repair site depends on the involvement and understanding of the technicians.
(b) Sorting. Sorting is the process of segregating different types of used oil so that it is not contaminated with other types of oil during transportation and storage. Sorting includes all activities and issues like regulations, warehousing, inventory management, etc that may affect the purity of collected oil and its unsolicited disposal. Proper sorting leads to better remunerations for the product.
(c) Transportation. This criterion includes all activities that affect the process of physical transportation of used oil from the service station to the store/ reclamation plant. Correct transportation policy can not only prevent wastage, reduce handling losses, reduce transportation cost and prevent further contamination of used oil.
(d) Reclamation. Recovery of used oil is technology driven and governed by many regulations including concerns for clean environmental. Reclamation reduces waste generation, reduces pollution and increases life of product. It also generates additional revenue for the exchequer.

The objective of the questionnaire is to evaluate the reason out ‘Should USED aviation oil be Recycled or Incinerated?’

From economic and environmental consideration reclamation supply chain should be optimized to ensure that maximum quantity of used oil reaches the recyclers/ reclaimers. Therefore, the objectives of the supply chain of used oil can be listed as follows: -
(a) Maximizing collection
(b) Reducing waste
(c) Preventing contamination and
(d) Reducing cost of transportation

The reclamation supply chain should be optimized to ensure that maximum quantity of used oil reaches the recyclers/ reclaimers. In your opinion, which factor in each set of comparisons stated below, have greater influence on the supply chain of used oil? *

	Extremly important	Strongly important	Moderately important	Slightly important	Equally important	Slightly less	Moderately less	St

	important	important	important	important	important	important	important	imp
Collection against Sorting	○	○	○	○	○	○	○	
Collection against Transportation	○	○	○	○	○	○	○	
Collection against Reclamation	○	○	○	○	○	○	○	
Sorting against Transportation	○	○	○	○	○	○	○	
Sorting against Reclamation	○	○	○	○	○	○	○	
Transportation against Reclamation	○	○	○	○	○	○	○	

Optimizing Collection Process

The quantity of used oil collected from the work-station/ repair site may be affected by various factors. According to inputs received from maintenance staff and shop floor management the volume of oil returned to store is influenced by the following factors: -
(a) Regulation- Absence of specific Regulations/ directives/ policies on accounting of each variety of used oil drained from aircraft as different inventory
(b) Training- Lack of training of technicians and storekeepers working on/ supervising the repair activity on safe handling of used oil
(c) Tools- Non-availability of specialized tools and shipping containers for draining and transporting the used oil improve the quantity of collection, by minimizing wastage, spillage and handling efforts
(d) Unsolicited use- Lack of explicit instruction on preventing disposal/ unsolicited use of used oil within the workshop/ organization like using it for anti-rust painting, lubricating tools and equipment, as cleaning agent, etc.

In your opinion, which factor in each set of comparisons stated below, would have greater influence on the quantity of used oil collected for reclamation and returned to store? *

	Extremly important	Strongly important	Moderately important	Slightly important	Equally important	Slightly less important	Moderately less important	Strong less import

Regulation against Training								
Regulation against Tools								
Regulation against Unsolicited use								
Training against Tools								
Training against Unsolicited use								
Tools against Unsolicited use								

Optimizing Sorting Process

The sorting process affects the quality of used oil returned to reclaimer as contamination by other types of oil/ fuel/ water/ grease/ etc may result in lower recovery rates. According to experts from reclamation industry, proper sorting can not only improve the recovery rate but also reduce carbon footprint. Few factors which may influence the sorting process are listed below: -

(a) Regulations/ directives/ policies on inventory management of used oil drained from aircraft.

(b) Warehousing effectiveness - which is defined as the material handling capability and warehousing strategy of a store.

(c) Inventory Carrying Cost - which includes all expense towards the management of inventory in storage.

In your opinion, which factor in each set of comparisons stated below, would have greater influence on the sorting process before being transported for reclamation? *

	Extremly important	Strongly important	Moderately important	Slightly important	Equally important	Slightly less important	Moderately less important	Stro le impo

Regulation against Warehouse effectiveness	○	○	○	○	○	○	○	○
Regulation against Inventory carrying cost	○	○	○	○	○	○	○	○
Warehousing effectiveness against Inventory carrying cost	○	○	○	○	○	○	○	○

Optimizing the Transportation Process

The efficiency of transportation process for the used oil for its movement from the store/ warehouse to the reclaimer will have a very significant influence on the sustainability of the reclamation process itself. According to expert transporters, the following factors affect the cost of transportation : -

(a) Transit Quantity.

(b) Transit Cost

In your opinion, which factor in each set of comparisons stated below, would have greater influence on the transportation component of the reverse supply chain of used oil? *

	Extremly important	Strongly important	Moderately important	Slightly important	Equally important	Slightly less important	Moderately less important	Strongly less importan
Transit Quantity against Transit Cost	○	○	○	○	○	○	○	○

Optimizing Reclamation Process

The Reclamation process for used aviation oil is technology driven and governed by many regulations including concerns for clean environmental. According to aviation experts the following reasons may influence the selection of reclamation option: -

(a) Availability of environmentally safe technology in the industry for reclamation of used

aviation oil
(b) Economy of effort and scale - strategic to employ minimum resources to obtain maximum output in commercial terms
(c) Regulation on disposal of waste (Hazardous and Other Wastes Rules, 2016).

In your opinion, which factor in each set of comparisons stated below, would have greater influence on selection of reclamation as the only option for disposal of used aviation oil? *

	Extremly important	Strongly important	Moderately important	Slightly important	Equally important	Slightly less important	Moderately less important	Stron less impor
Technology against Economy	○	○	○	○	○	○	○	○
Technology against Regulation	○	○	○	○	○	○	○	○
Economy against Regulation	○	○	○	○	○	○	○	○

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SUBMIT

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor amongst the following has the greatest influence on the efficacy of RSC of used aviation oil.					
	List of Respondents	Collection Vs Sorting	Collection Vs Trans	Collection Vs Reclm	Sorting Vs Trans	Sorting Vs Reclm	Trans Vs Reclm
1	Principal Director, Dte Maint Plans	1.000	8.000	2.000	2.000	0.800	0.125
2	Principal Director, Dte Ops Lgs	1.000	7.000	1.000	4.000	0.200	0.111
3	Principal Director, Dte of Store	2.000	7.000	1.000	3.000	0.167	0.167
4	Dir, Dte of Maint Plan	1.000	9.000	1.000	2.000	0.125	0.125
5	Dir, Dte of Engg Western Transport	1.000	8.000	2.000	5.000	0.667	1.000
6	Dir, Dte of Engg Russian	4.000	8.000	1.000	2.000	0.250	0.167
7	Dir, Dte of Engg Russian Fighter	1.000	7.000	0.500	5.000	1.000	0.167
8	Chief Engg Officer, Srinagar	2.000	8.000	25.000	7.000	2.000	0.330
9	Chief Engg Officer, Udhampur	2.000	7.000	1.000	3.000	0.167	0.167
10	Chief Engg Officer, Pathankot	4.000	7.000	1.000	6.000	1.000	0.111
11	Chief Engg Officer, Adampur	6.000	8.000	1.000	2.000	0.500	0.250
12	Chief Engg Officer, Halwara	2.000	7.000	1.000	3.000	0.167	0.167
13	Chief Engg Officer, Chandigarh	9.000	9.000	1.000	1.000	0.125	0.125
14	Chief Engg Officer, Ambala	7.000	9.000	1.000	1.000	0.111	0.167
15	Chief Engg Officer, Bhatinda	6.000	8.000	1.000	2.000	0.500	0.250
16	Chief Engg Officer, Sarsawa	2.000	7.000	1.000	3.000	0.167	0.167
17	Chief Engg Officer, Sirsa	9.000	5.000	1.000	4.000	0.143	0.167
18	Chief Engg Officer, Suratgarh	6.000	8.000	1.000	2.000	0.500	0.250
19	Chief Engg Officer, Hindon	7.000	9.000	1.000	6.000	0.200	0.125
20	Chief Engg Officer, Bareily	7.000	7.000	1.000	1.000	0.500	0.125
21	Chief Engg Officer, Agra	9.000	8.000	1.000	1.000	0.111	0.167
22	Chief Engg Officer, Gwalior	6.000	8.000	1.000	2.000	0.500	0.250

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor amongst the following has the greatest influence on the efficacy of RSC of used aviation oil.					
	List of Respondents	Collection Vs Sorting	Collection Vs Trans	Collection Vs Reclm	Sorting Vs Trans	Sorting Vs Reclm	Trans Vs Reclm
23	GM (Maint), Air India, Delhi	9.000	9.000	1.000	6.000	0.143	0.143
24	GM (Maint), Indigo, Gurgoan	7.000	7.000	1.000	6.000	0.200	0.167
25	CEO, GMR Aero Technic Ltd	7.000	9.000	1.000	6.000	0.200	0.125
26	Sr Instructor, Airbus Trg center	9.000	9.000	1.000	8.000	0.167	0.125
27	Dir Gen POL, ASC, Army HQ	4.000	9.000	2.000	2.000	1.000	0.125
28	Dir Supply & Transport, Army HQ	1.000	8.000	2.000	4.000	0.200	0.111
29	Mr BK Sharma, Div Head, WMD-II	4.000	8.000	2.000	3.000	1.000	0.167
30	Ms PK Selvi, Sc D, WMD-II, MoE&F	4.000	9.000	2.000	2.000	1.000	0.125
31	Executive Director, PCRA	5.000	8.000	2.000	5.000	0.500	0.333
32	Dir R&D, PCRA	5.000	7.000	1.000	4.000	0.250	0.330
33	Dir, MOCL, Kanpur	7.000	7.000	1.000	6.000	0.200	0.167
34	DDG, DGCA	7.000	9.000	1.000	6.000	0.200	0.125
35	Dy Dir AW, DGCA	6.000	8.000	4.000	2.000	1.000	0.250
36	Dir FOL, DGAQA	7.000	9.000	1.000	6.000	0.200	0.125
37	RD (F&F, POL), RCMA, CEMILAC	4.000	9.000	2.000	2.000	1.000	0.125
38	Dy Dir (Stat), DGCA	5.000	7.000	4.000	4.000	0.500	0.167
39	Dir Aircraft Engg, DGCA	4.000	8.000	1.000	1.000	0.500	0.125
40	MD Aviation, IOCL	3.000	7.000	0.500	0.125	4.000	0.125
41	Pr Scientist, Lubes, CSIR-IIP	7.000	9.000	1.000	6.000	0.200	0.125
42	Professor, Operation & SC, NITIE	7.000	7.000	1.000	6.000	0.200	0.167
	Geometric Mean =	4.026	7.848	1.273	2.902	0.348	0.167
	Assigned Weight =	**4.000**	**8.000**	**1.000**	**3.000**	**0.333**	**0.167**

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor amongst the following has the greatest influence on the collection of used aviation oil.					
	List of Respondents	Reg Vs Trg	Reg Vs Spl Ts	Reg Vs Dspsl	Trg Vs Spl Ts	Trg Vs Dspsl	Spl Ts Vs Dspsl
1	Principal Director, Dte Maint Plans	3.000	7.000	7.000	2.000	4.000	0.250
2	Principal Director, Dte Ops Lgs	3.000	7.000	7.000	4.000	5.000	0.500
3	Principal Director, Dte of Store	3.000	5.000	7.000	2.000	4.000	0.333
4	Dir, Dte of Maint Plan	3.000	7.000	7.000	3.000	4.000	0.500
5	Dir, Dte of Engg Western Transport	2.000	7.000	5.000	1.000	2.000	1.000
6	Dir, Dte of Engg Russian	1.000	6.000	6.000	2.000	4.000	0.143
7	Dir, Dte of Engg Russian Fighter	2.000	5.000	4.000	1.000	3.000	0.500
8	Chief Engg Officer, Srinagar	1.000	4.000	3.000	0.500	2.000	0.125
9	Chief Engg Officer, Udhampur	3.000	5.000	7.000	3.000	4.000	0.500
10	Chief Engg Officer, Pathankot	2.000	4.000	6.000	1.000	4.000	0.250
11	Chief Engg Officer, Adampur	2.000	5.000	4.000	2.000	5.000	0.333
12	Chief Engg Officer, Halwara	3.000	5.000	7.000	1.000	4.000	0.500
13	Chief Engg Officer, Chandigarh	2.000	4.000	5.000	1.000	6.000	0.167
14	Chief Engg Officer, Ambala	5.000	4.000	7.000	2.000	8.000	0.250
15	Chief Engg Officer, Bhatinda	2.000	5.000	4.000	2.000	5.000	0.333
16	Chief Engg Officer, Sarsawa	3.000	5.000	7.000	1.000	4.000	0.500
17	Chief Engg Officer, Sirsa	5.000	3.000	4.000	1.000	2.000	0.500
18	Chief Engg Officer, Suratgarh	2.000	5.000	4.000	2.000	5.000	0.333
19	Chief Engg Officer, Hindon	4.000	7.000	5.000	2.000	7.000	0.250
20	Chief Engg Officer, Bareily	4.000	2.000	4.000	1.000	4.000	0.167
21	Chief Engg Officer, Agra	4.000	7.000	5.000	2.000	1.000	3.000
22	Chief Engg Officer, Gwalior	2.000	5.000	4.000	2.000	5.000	0.333

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor amongst the following has the greatest influence on the collection of used aviation oil.					
	List of Respondents	Reg Vs Trg	Reg Vs Spl Ts	Reg Vs Dspsl	Trg Vs Spl Ts	Trg Vs Dspsl	Spl Ts Vs Dspsl
23	GM (Maint), Air India, Delhi	2.000	5.000	3.000	1.000	8.000	0.200
24	GM (Maint), Indigo, Gurgoan	7.000	6.000	3.000	2.000	3.000	1.000
25	CEO, GMR Aero Technic Ltd	4.000	7.000	5.000	2.000	7.000	0.500
26	Sr Instructor, Airbus Trg center	3.000	5.000	4.000	3.000	5.000	0.200
27	Dir Gen POL, ASC, Army HQ	3.000	7.000	9.000	4.000	4.000	0.500
28	Dir Supply & Transport, Army HQ	3.000	5.000	8.000	3.000	5.000	2.000
29	Mr BK Sharma, Div Head, WMD-II	3.000	7.000	9.000	4.000	4.000	3.000
30	Ms PK Selvi, Sc D, WMD-II, MoE&F	3.000	7.000	9.000	4.000	4.000	3.000
31	Executive Director, PCRA	3.000	7.000	5.000	3.000	4.000	5.000
32	Dir R&D, PCRA	3.000	8.000	5.000	2.000	4.000	1.000
33	Dir, MOCL, Kanpur	4.000	4.000	7.000	3.000	8.000	2.000
34	DDG, DGCA	4.000	7.000	5.000	2.000	7.000	0.250
35	Dy Dir AW, DGCA	1.000	5.000	6.000	4.000	5.000	2.000
36	Dir FOL, DGAQA	4.000	7.000	5.000	2.000	7.000	0.250
37	RD (F&F, POL), RCMA, CEMILAC	3.000	7.000	9.000	4.000	4.000	0.500
38	Dy Dir (Stat), DGCA	1.000	3.000	6.000	2.000	7.000	0.333
39	Dir Aircraft Engg, DGCA	1.000	5.000	7.000	2.000	4.000	1.000
40	MD Aviation, IOCL	5.000	4.000	3.000	4.000	1.000	0.500
41	Pr Scientist, Lubes, CSIR-IIP	4.000	7.000	5.000	2.000	7.000	1.000
42	Professor, Operation & SC, NITIE	4.000	4.000	7.000	3.000	8.000	0.333
	Geometric Mean =	2.716	5.292	5.425	2.003	4.285	0.520
	Assigned Weight =	**3.000**	**6.000**	**6.000**	**2.000**	**4.000**	**0.500**

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor has the greatest influence on the sorting process at warehouse			Which factor has the greatest influence on the transport efficiency
	List of Respondents	Reg Vs W/housing	Reg Vs Carrying cost	W/housing Vs C/ing Cost	Qty Vs Dist
1	Principal Director, Dte Maint Plans	9.000	0.143	4.000	0.111
2	Principal Director, Dte Ops Lgs	9.000	0.125	4.000	0.200
3	Principal Director, Dte of Store	9.000	0.125	1.000	0.200
4	Dir, Dte of Maint Plan	7.000	0.125	1.000	0.143
5	Dir, Dte of Engg Western Transport	7.000	0.111	1.000	0.167
6	Dir, Dte of Engg Russian	7.000	0.125	4.000	0.167
7	Dir, Dte of Engg Russian Fighter	8.000	0.125	0.500	0.143
8	Chief Engg Officer, Srinagar	8.000	0.125	4.000	0.250
9	Chief Engg Officer, Udhampur	9.000	4.000	1.000	0.200
10	Chief Engg Officer, Pathankot	9.000	6.000	0.500	0.125
11	Chief Engg Officer, Adampur	8.000	5.000	1.000	0.143
12	Chief Engg Officer, Halwara	9.000	5.000	1.000	0.200
13	Chief Engg Officer, Chandigarh	7.000	4.000	1.000	0.167
14	Chief Engg Officer, Ambala	6.000	6.000	3.000	0.143
15	Chief Engg Officer, Bhatinda	8.000	7.000	4.000	0.143
16	Chief Engg Officer, Sarsawa	9.000	7.000	4.000	0.200
17	Chief Engg Officer, Sirsa	5.000	8.000	4.000	0.250
18	Chief Engg Officer, Suratgarh	8.000	5.000	1.000	0.143
19	Chief Engg Officer, Hindon	8.000	5.000	2.000	0.250
20	Chief Engg Officer, Bareily	5.000	8.000	0.500	0.333
21	Chief Engg Officer, Agra	4.000	3.000	1.000	0.200
22	Chief Engg Officer, Gwalior	8.000	9.000	1.000	0.143

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor has the greatest influence on the sorting process at warehouse			Which factor has the greatest influence on the transport efficiency
	List of Respondents	Reg Vs W/housing	Reg Vs Carrying cost	W/housing Vs C/ing Cost	Qty Vs Dist
23	GM (Maint), Air India, Delhi	6.000	9.000	2.000	0.500
24	GM (Maint), Indigo, Gurgoan	7.000	9.000	1.000	0.167
25	CEO, GMR Aero Technic Ltd	8.000	7.000	2.000	0.250
26	Sr Instructor, Airbus Trg center	8.000	7.000	1.000	0.200
27	Dir Gen POL, ASC, Army HQ	4.000	8.000	0.500	0.167
28	Dir Supply & Transport, Army HQ	5.000	9.000	0.500	0.143
29	Mr BK Sharma, Div Head, WMD-II	5.000	8.000	0.333	0.143
30	Ms PK Selvi, Sc D, WMD-II, MoE&F	4.000	8.000	0.500	0.200
31	Executive Director, PCRA	4.000	8.000	0.250	0.250
32	Dir R&D, PCRA	4.000	9.000	0.330	0.143
33	Dir, MOCL, Kanpur	5.000	9.000	0.167	0.250
34	DDG, DGCA	8.000	9.000	2.000	0.333
35	Dy Dir AW, DGCA	3.000	2.000	0.250	0.200
36	Dir FOL, DGAQA	8.000	5.000	2.000	0.143
37	RD (F&F, POL), RCMA, CEMILAC	4.000	8.000	0.500	0.500
38	Dy Dir (Stat), DGCA	3.000	4.000	0.200	0.167
39	Dir Aircraft Engg, DGCA	4.000	3.000	0.200	0.250
40	MD Aviation, IOCL	7.000	5.000	0.125	0.200
41	Pr Scientist, Lubes, CSIR-IIP	8.000	5.000	2.000	0.250
42	Professor, Operation & SC, NITIE	5.000	4.000	0.167	0.125
	Geometric Mean =	6.277	2.877	0.915	0.192
	Assigned Weight =	**6.000**	**3.000**	**1.000**	**0.200**

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor has the greatest influence on enforcing collection for reclamation		
	List of Respondents	Tech Vs Econmy	Tech Vs Regs	Econmy Vs Regs
1	Principal Director, Dte Maint Plans	3.000	0.125	0.125
2	Principal Director, Dte Ops Lgs	5.000	0.125	0.111
3	Principal Director, Dte of Store	5.000	0.143	0.111
4	Dir, Dte of Maint Plan	4.000	0.167	0.125
5	Dir, Dte of Engg Western Transport	4.000	0.250	0.143
6	Dir, Dte of Engg Russian	3.000	0.500	0.111
7	Dir, Dte of Engg Russian Fighter	3.000	0.333	0.143
8	Chief Engg Officer, Srinagar	4.000	0.500	0.125
9	Chief Engg Officer, Udhampur	5.000	0.143	0.111
10	Chief Engg Officer, Pathankot	5.000	0.500	0.125
11	Chief Engg Officer, Adampur	5.000	0.167	0.111
12	Chief Engg Officer, Halwara	5.000	0.143	0.111
13	Chief Engg Officer, Chandigarh	3.000	0.250	0.125
14	Chief Engg Officer, Ambala	3.000	0.250	0.143
15	Chief Engg Officer, Bhatinda	5.000	0.167	0.111
16	Chief Engg Officer, Sarsawa	5.000	0.143	0.111
17	Chief Engg Officer, Sirsa	5.000	0.167	0.125
18	Chief Engg Officer, Suratgarh	5.000	0.167	0.111
19	Chief Engg Officer, Hindon	5.000	0.167	0.125
20	Chief Engg Officer, Bareily	3.000	0.143	0.111
21	Chief Engg Officer, Agra	4.000	0.200	0.125
22	Chief Engg Officer, Gwalior	5.000	0.167	0.111

RESPONSES FROM EXPERTS

Sl No	Questions to the Experts	Which factor has the greatest influence on enforcing collection for reclamation		
	List of Respondents	Tech Vs Econmy	Tech Vs Regs	Econmy Vs Regs
23	GM (Maint), Air India, Delhi	6.000	0.167	0.111
24	GM (Maint), Indigo, Gurgoan	4.000	0.250	0.143
25	CEO, GMR Aero Technic Ltd	5.000	0.167	0.125
26	Sr Instructor, Airbus Trg center	4.000	0.200	0.111
27	Dir Gen POL, ASC, Army HQ	4.000	0.250	0.125
28	Dir Supply & Transport, Army HQ	4.000	0.500	0.111
29	Mr BK Sharma, Div Head, WMD-II	4.000	0.500	0.111
30	Ms PK Selvi, Sc D, WMD-II, MoE&F	4.000	0.250	0.125
31	Executive Director, PCRA	4.000	0.200	0.143
32	Dir R&D, PCRA	2.000	1.000	0.250
33	Dir, MOCL, Kanpur	4.000	0.125	0.143
34	DDG, DGCA	5.000	0.167	0.125
35	Dy Dir AW, DGCA	5.000	0.167	0.111
36	Dir FOL, DGAQA	5.000	0.167	0.125
37	RD (F&F, POL), RCMA, CEMILAC	4.000	0.250	0.125
38	Dy Dir (Stat), DGCA	5.000	0.167	0.125
39	Dir Aircraft Engg, DGCA	3.000	0.143	0.111
40	MD Aviation, IOCL	8.000	5.000	0.125
41	Pr Scientist, Lubes, CSIR-IIP	5.000	0.167	0.125
42	Professor, Operation & SC, NITIE	4.000	0.125	0.143
	Geometric Mean =	4.236	0.225	0.124
	Assigned Weight =	**4.000**	**0.200**	**0.125**

CALCULATION SHEET: FACTOR-MAIN

Factors influencing efficacy of RSC					
Factor	**Col**	**Sort**	**Transp**	**Reclm**	**Total**
Col	1.000	0.250	0.125	1.000	2.375
Sort	4.000	1.000	0.333	3.000	8.333
Transp	8.000	3.000	1.000	6.000	18.000
Reclm	1.000	0.333	0.167	1.000	2.500
Total	14.000	4.583	1.625	11.000	

Factor	**c1**	**c2**	**c3**	**c4**	**Total**	**Average (Weight)**	**Consistancy Measure**
c1	0.071	0.055	0.077	0.091	0.294	0.073	4.000
c2	0.286	0.218	0.205	0.273	0.982	0.245	4.039
c3	0.571	0.655	0.615	0.545	2.387	0.597	4.067
c4	0.071	0.073	0.103	0.091	0.338	0.084	4.018
	$\lambda =$	4.031		Consistency Index =			**0.010**
	CI=	0.01036		Random Index for M 4X4 =			**0.900**
				Consistecy Ratio =			**0.012**

CALCULATION SHEET: FACTOR-COLLECTION

Factors influencing efficacy of Collection					
Factor	**Reg**	**Trg**	**Spl Tool**	**Disp**	**Total**
Reg	1.000	0.333	0.167	0.167	1.667
Trg	3.000	1.000	0.500	0.250	4.750
Spl Tool	6.000	2.000	1.000	2.000	11.000
Disp	6.000	4.000	0.500	1.000	11.500
Total	16.000	7.333	2.167	3.417	

Factor	**c1**	**c2**	**c3**	**c4**	**Total**	**Average (Weight)**	**Consistancy Measure**
c1	0.063	0.045	0.077	0.049	0.234	0.058	4.134
c2	0.188	0.136	0.231	0.073	0.628	0.157	4.041
c3	0.375	0.273	0.462	0.585	1.695	0.424	4.272
c4	0.375	0.545	0.231	0.293	1.444	0.361	4.297
	$\lambda =$	4.186		Consistency Index =			**0.062**
	CI=	0.06206		Random Index for M 4X4 =			**0.900**
				Consistecy Ratio =			**0.069**

CALCULATION SHEET: FACTOR-SORTING

Factors influencing efficacy of Sorting				
Factor	**Reg**	**W/Housing**	**C/Cost**	**Total**
Reg	1.000	0.167	0.333	1.500
Trg	6.000	1.000	1.000	8.000
Spl Tool	3.000	1.000	1.000	5.000
Total	10.000	2.167	2.333	

Factor	c1	c2	c3	Total	Average (Weight)	Consistancy Measure
c1	0.100	0.077	0.143	0.320	0.107	3.017
c2	0.600	0.462	0.429	1.490	0.497	3.086
c3	0.300	0.462	0.429	1.190	0.397	3.058
	$\lambda =$	3.054	Consistency Index =			**0.027**
	CI=	0.0269395	Random Index for M 3X3 =			**0.580**
			Consistecy Ratio =			**0.046**

CALCULATION SHEET: FACTOR-TRANSPORTATION

Factors influencing efficacy of Sorting			
Factor	**Qty**	**Dist**	**Total**
Qty	1.000	5.000	6.000
Dist	0.200	1.000	1.200
Total	1.200	6.000	

Factor	c1	c2	Total	Average (Weight)	Consistancy Measure
c1	0.833	0.833	1.667	0.833	2.000
c2	0.167	0.167	0.333	0.167	2.000
$\lambda =$	2.000	Consistency Index =			**0.000**
CI=	0	Random Index for M 2X2 =			**0.000**
		Consistecy Ratio =			**0.000**

CALCULATION SHEET: FACTOR-RECLAMATION

Factors influencing efficacy of Reclamation				
Factor	**Tech**	**Economics**	**Regs**	**Total**
Tech	1.000	0.250	5.000	6.250
Econm	4.000	1.000	8.000	13.000
Regs	0.200	0.125	1.000	1.325
Total	5.200	1.375	14.000	

Factor	**c1**	**c2**	**c3**	**Total**	**Average (Weight)**	**Consistancy Measure**
c1	0.192	0.182	0.357	0.731	0.244	3.080
c2	0.769	0.727	0.571	2.068	0.689	3.191
c3	0.038	0.091	0.071	0.201	0.067	3.016
	$\lambda =$	3.096	Consistency Index =			**0.048**
	CI=	0.04781567	Random Index for M 3X3 =			**0.580**
			Consistecy Ratio =			**0.082**

CALCULATION SHEET: GLOBAL WEIGHT

Primary Factor	**Local Weight**	**Secondary Factor**	**Local Weight**	**Global Weight**	**Global Rank**
Collection	0.073	Regulation	0.058	0.004234	12
		Training	0.157	0.011461	10
		Spl Tools	0.424	0.030952	6
		Disposal	0.361	0.026353	7
Consistency check for ‘Collection’- CI= 0.062, RI= 0.9, CR= 0.069, for n=4					
Sorting	0.245	Regulation	0.107	0.026215	8
		Warehousing	0.497	0.121765	2
		Carrying Cost	0.397	0.097265	4
Consistency check for ‘Sorting’- CI= 0.027, RI= 0.58, CR= 0.046, for n=3					
Transportation	0.597	Quantity	0.833	0.49730	1
		Distance	0.167	0.09970	3
Consistency check for ‘Transportation’- CI= 0, RI= 0, CR= N/A, for n=2					
Reclamation	0.084	Technology	0.244	0.02050	9
		Economics	0.689	0.05788	5
		Regulation	0.067	0.00563	11
Consistency check for ‘Reclaim’- CI= 0.047, RI= 0.58, CR= 0.082, for n=3					
Consistency check for Primary Factors- CI= 0.0104, RI= 0.90, CR= 0.012, for n=4					

CURRICULUM VITAE

Personal Details:

Asheesh Shrivastava

Group Captain, Project Director

Directorate of Indigenisation, Air Headquarters, West Block VI,

Sector 1, RK Puram, New Delhi 110066

Mobile: +91 96500 30808

Email: asheesh1470@gmail.com

pobio.fuel@gov.in

Professional Experience

- Project Director, Indigenisation, Bio-jet fuel project, Air Headquarters, New Delhi, October 2019- till date. Responsible for conceiving and implementing various R&D projects that promote indigenisation and reduce import dependency in the IAF.
- Joint Director, Directorate of Maintenance Plans, Air Headquarters, New Delhi, July 2012- July 2016. Was responsible for the management and allocation of technical resources including manpower to various operational units of the IAF, also responsible for review and implementation of HR polices of IAF i.r.o. engineering branch.
- Senior Engineer (Aircraft), Air Force Station, Nagpur, June 2009- July 2012. Directly responsible to oversee all aircraft related technical activities of the operational station.
- Engineering Officer, 78 Squadron, Agra, December 2002-July 2006. Was amongst the first batch of officers to raise IAF's first Air to Air aircraft refuelling squadron in Mar 2003. As part of pioneers visited various friendly foreign nations including USA, Israel, Uzbekistan and Russia for training programs and operational exercises.

- Engineering Officer, 44 Squadron, Agra and 25 Squadron, Chandigarh, February 1998- December 2002. While posted to the operational squadron, was actively involved in all activities during the Kargil Conflict (1999) and high altitude operations ex-Leh.

Academic Experience

- Research Scholar, Centre for Air Power Studies, Subroto Park, New Delhi, April 2017- October 2019. Engaged in exploring the topic 'Energy resilience in Military Affairs', which aimed a suggesting options to reduce India's dependence on imported energy for sustainable growth. Proposed innovative project for testing bio-jet fuel on Indian military aircraft.
- Chief Instructor, IL 76/78/ AWACS TETTRA School, Agra, August 2016- April 2017. Responsible for imparting specialised professional (technical) training to engineers and technicians of the IAF.
- Chief Instructor, Mechanical Training Institute, Tambaram, Chennai, July 2006 – June 2009. Responsible for imparting ab-initio training to young technicians of aviation trade including, airframe, engine and weapon streams of the IAF.

Professional Qualification

- AWACS aircraft maintenance engineers course - 2011
- Explosive Ordnance Disposal Course - 2011
- Senior Engineers' Management Orientation Course - 2010
- Method of Instruction Course - 2006
- Air Armament Course - 2005
- IL 78 aircraft system modernisation course, Uzbekistan - 2004
- Maintenance Training on ARP-3 POD, Israel - 2003
- Flight and Maintenance Safety Course - 1999

- Para Descent Course - 1998
- IL 76 aircraft maintenance engineers course - 1998

Academic Qualification (Courses, workshop, Training Program)

- Master in Business Administration (Operations Management) - 2013
- Diploma in Cyber Law - 2012
- Master in Computer Application - 2009
- Post Graduate Diploma in Computer Application - 2007
- Proficiency Course in Russian Language – 1999
- Aeronautical Engineering (Mechanical), AFTC, Bangalore - 1996
- BE (Mechanical), RDVV (Jabalpur University), MP - 1993

Research/ Innovation Projects

- Reclamation of Used Hydraulic Oil. Sponsored a development project, through the IAF indigenisation fund, for the development of technology for reclamation of over four lac litres of used aviation grade Hydraulic Oil. On certification and commercialisation of this technology, IAF would not only save precious foreign exchange but also reduce the environmental impact of waste oil disposal.
- Development and testing of indigenous bio-jet fuel. Conceived in 2017, the project envisaged the development, testing, certification and flight trials towards sustainable use of bio-jet fuel in military and civil aviation. IAF's AN-32 aircraft powered with bio-jet mixed fuel on the Republic Day flypast in 2019 and later from Leh Airport on 30 January 2020. The innovation for awarded by the Prime Minister on 09 October 2019, for its innovative content.
- Design of safety harness for recovery of small tools. While working in congested spaces of aircraft, tool drop into inaccessible area results in major

technical holdups. An inventive safety harness designed to enable easy recovery of such small tools was awarded cash prize for innovation by Senior Maintenance Staff Officer, Central Air Command, on 01 March 2012.

Research Publications

- Synthesizing Indigenisation: Civil- Defence Aviation Partnership towards Self Reliance, Asheesh Shrivastava, Article, 11 June 2020, Vivekananda International Foundation, New Delhi
- Does reclaiming used oil make economic sense for India? Asheesh Shrivastava, Asian Defence Review 2019, RW Publication, New Delhi
- Military's Role in Energy Security: A Strategic Review, Asheesh Shrivastava, Air Power Journal, Volume 14 No 2, Apr-Jun 2019, Centre for Air Power Studies, new Delhi
- Issue Brief: Aviation economics to agrarian trepidation: Can bio-jet provide a balanced solution? Asheesh Shrivastava, 23 January 2019, CAPS publication, New Delhi
- In focus: IAF's maiden flight takes wings with indigenous bio-jet fuel, Asheesh Shrivastava, 17 December 2018, CAPS publication, New Delhi
- Issue Brief: Biofuel Day-IAF's Contribution, Asheesh Shrivastava, 14 August 2018, CAPS publication, New Delhi
- Managing Crude: A Challenge for India's Energy Basket, Asheesh Shrivastava, Defence and Diplomacy, Volume 7 No 3, Apr-Jun 2018, Centre for Air Power Studies, New Delhi
- Mass Attack by Drones: Facing the Challenge, article in Air Power Journal, Vol 13 No 2, Asheesh Shrivastava, Knowledge World Publications Pvt Ltd, 2018, New Delhi
- Sustaining Air Operations: Renewed Interest in Biofuel, Asheesh Shrivastava, Asian Defence Review 2018, RW Publication, New Delhi

- Cyber Astuteness: An Elusive Enabler of Military Dominance, Air Power Journal, Vol.12, No.4, Winter 2017, Asheesh Shrivastava, KW Publications Pvt Ltd, New Delhi
- Issue Brief, Directed Energy Weapons: Safety of Airborne Platform, Asheesh Shrivastava, 29 June 2017, CAPS publication, New Delhi
- In Focus, Where's the money honey? Are Indian ATMs vulnerable to Cyber Attack, Asheesh Shrivastava, Issue No-43/17, 17 May 2017, CAPS publication, New Delhi
- In Focus, Can China cause Power outage in India: Operation Blackout, Asheesh Shrivastava, Issue No-40/17, 15 May 2017, CAPS publication, New Delhi
- Recycling of Products Causing Pollution: A Suggestive Reverse Supply Chain Model for India, Asheesh Shrivastava, Liberal Studies Journal (LSJ), Volume-2, Issue 1, Jan-Jun 2017
- Expanding Margins: Reclaiming Aviation Grade Lubrication Oils, Asheesh Shrivastava, International Journal of Engineering and Applied Sciences (IJEAS), Volume-2, Issue-7, July 2015

Participation in Seminar/ Workshop/ Training Programs

- 'Supply Chain Management', National Institute of Industrial Engineering (NITIE), Mumbai- 2016.
- 'Aircraft Maintenance with Zero Error', Society of Indian Aerospace Technologies and Industries, Bangalore – 2017.
- 'Interpersonal Effectiveness and Team Building', Indian Institute of Management (IIM), Indore - 2012
- 'Leadership and Behaviour Sciences', C-LABS, Secunderabad – 2007
- 'Mentoring Skills', HAL Management Academy, Bangalore - 2006

Professional Awards

- IAF National Award for best innovation by Prime Minister in 2019
- Chief of Air Staff commendation awarded in 2019
- 'Category A' awarded for technical excellence by IAF Maintenance Officers' Categorisation Board in 2016
- Vice Chief of Air Staff commendation awarded in 2014
- SMSO, CAC, award for excellence in innovation in 2012
- Appreciation by AOC, Air Force Station, Tambaram in 2010
- AOC-in-C, CAC commendation awarded in 2000

Academic Recognition

- Panellist, 'Novel Concepts, Bio-refineries, Bio-chemicals, Renewable Fuels and CCU', 3rd EU-India Conference on Advanced Biofuels, New Delhi, 02 March 2020.
- Panellist, 'Aviation Biofuels for sustainable Future', World Future Fuel Summit 2020, New Delhi, 15 February 2020
- Expert Speaker at 'Recent Developments in Renewable Energy Systems', Faculty Development Program, conducted by Delhi Technology University, New Delhi, 25 November 2019
- Expert Speaker on 'Using LCA to optimize RSC for collection of Used Oil: Case study of aviation lubricants' at Indian Institute of Management, Kashipur, 07 June 2019
- Participant 'Round Table on Progressing Circular Economy in India', FICCI, New Delhi, 09 April 2019.
- Panellist in live TV show, 'Vaad Samvad: Bio-jet Special', Doordarshan, New Delhi, 31 January 2019

- Expert Speaker on ‘Understanding Development – Strategic Consideration & Supply Chains’, Global Sustainable Aviation Fuels Summit, organized by ACI & Ministry of Civil Aviation, New Delhi, 28 January 2019
- Expert Speaker on ‘Sustaining Bio-jet fuel in India: The Flight Plan’, Global Refining & Petrochemicals Congress, New Delhi, 17 July 2018
- Expert Speaker at 29th Working Group on Bio-Fuel, Steering Committee on Bio-fuel, Ministry of Petroleum and Natural Gas, 10 January 2018
- Expert Speaker on ‘Small & Silent Aerial Attackers – Facing the Drone Challenge’, Indian Defence Conclave-2018, New Delhi, 07 December 2018.
- Expert Speaker on ‘Can Life Cycle knowledge increase potential of Used Oil’, Indian Conference on Life Cycle Management (ILCM 2018), FICCI Seminar, Mumbai, 04 October 2018

Membership

- Principal Member, Committee on automotive, aviation and industrial fuels, PCD 3.1, Bureau of Indian Standards, N Delhi
- Member, ‘National Sub-Committee on Bio-jet Fuel’, Ministry of Petroleum and Natural Gas, N Delhi
- Member, The Aeronautical Society of India, N Delhi
- Member, Institute of Engineers, Bhopal Chapter

Personal Details

Father’s Name	:	Shri Vijay K Shrivastava
Date of Birth	:	14th August, 1970
Languages known	:	English, Hindi, Bengali
Permanent Address	:	53, Narayan Nagar, Hoshangabad Road Opposite Barkatulla University Campus, Bhopal, MP, 462023

Declaration

Certified that the above mentioned information are true to best of my knowledge and understanding.

Shrivastava

Place : Delhi (Asheesh Shrivastava)

LIST OF PUBLICATION

<table>
<tr><th colspan="5">DETAILS ON PHD SCHOLARS, SUPERVISOR AND PUBLICATIONS</th></tr>
<tr><th colspan="2">Name of Supervisor</th><th>Name of Scholar</th><th colspan="2">SAP Id</th></tr>
<tr><td>Dr Prasoom Dwivedi Supervisor</td><td>Dr Saurabh Tiwari Co-Supervisor</td><td>Asheesh Shrivastava</td><td colspan="2">500025126</td></tr>
</table>

Sl No	Details of Publication (Name of author, name of journal, volume, issue, page and year)	Indexing Details
1.	Expanding Margins: Reclaiming Aviation Grade Lubrication Oils, Asheesh Shrivastava, Dr Yogita Khare International Journal of Engineering and Applied Sciences (IJEAS), Volume-2, Issue-7, July 2015	ISSN:2394-3661
2.	Recycling of Products Causing Pollution: A Suggestive Reverse Supply Chain Model for India, Asheesh Shrivastava, Dr Yogita Khare, Liberal Studies Journal (LSJ), Volume-2, Issue 1, Jan-Jun 2017	ISSN 2455-9857
3.	Sustaining Air Operations: Renewed Interest in Biofuel, Asheesh Shrivastava, Asian Defence Review 2018	ISBN 978-93-87324-36-7
4.	Managing Crude: A Challenge for India’s Energy Basket, Asheesh Shrivastava, Defence and Diplomacy, Volume 7 No 3, Apr-Jun 2018	ISSN 2347-3703
5.	Military’s Role in Energy Security: A Strategic Review, Asheesh Shrivastava, Air Power Journal, Volume 14 No 2 Apr-Jun 2019	ISBN 81-87966-30-0
6.	Does reclaiming used oil make economic sense for India? Asheesh Shrivastava, Asian Defence Review 2019	ISBN 978-93-89137-20-0

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Sources included in the report

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J	**Identification of Environmental Criteria for Selecting a Logistics Service Provider: A Step Forward towards Green Supply Chain Management** URL: 770a0443-df30-4d26-bef1-66e4708b8d90 Fetched: 10/16/2019 11:00:48 AM	1
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SA	**THESIS_2K11-Phd-ME-06.pdf** Document THESIS_2K11-Phd-ME-06.pdf (D20641754)	1
W	URL: https://sls.pdpu.ac.in/downloads/Asheesh%20Shrivastava,%20Yogita%20Khare.pdf Fetched: 2/14/2020 11:52:44 AM	40
W	URL: http://125.21.248.139/images/pdf/impleofest.pdf Fetched: 12/13/2020 10:41:00 AM	2
W	URL: https://ttu-ir.tdl.org/ttu-ir/bitstream/handle/2346/11060/31295017977819.pdf?seque ... Fetched: 5/26/2020 7:45:11 PM	1