KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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WASTE SORTING OPTIMIZATION IN AIRCRAFT MAINTENANCE: IMPLEMENTATION OF LEAN MANUFACTURING

Final project for Master's degree

Supervisor:
Assoc. Prof. dr. Kęstutis Pilkauskas

KAUNAS, 2016

KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN
PRODUCTION ENGINEERING DEPARTMENT

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Industrial Engineering and Management
(M5106M21)

Project made by
Matas Valentinavičius

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INDUSTRIAL ENGINEERING AND MANAGEMENT (M5106M21)

WASTE SORTING OPTIMIZATION IN AIRCRAFT MAINTENANCE: IMPLEMENTATION OF LEAN MANUFACTURING

DECLERATION OF ACADEMIC INTEGRITY

29 MAY 2016

I confirm that the final project of mine, **Matas Valentinavičius**, on the subject "Waste sorting optimization in aircraft maintenance: implementation of Lean manufacturing" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, internet-based or otherwise recorded source. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis. I fully and completely understand that any discovery of any manifestations/cases/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology

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FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Approved:

Head of Production engineering Department	(Signature, date)
	Kazimieras Juzėnas *(Name, Surname)*

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Waste sorting optimization in aircraft maintenance: implementation of Lean manufacturing

Approved by the Dean Order No.V25-11-7, 3 May 2016

2. Aim of the project

Evaluate and decide efficient waste sorting solution and implement Lean manufacturing methods on aircraft maintenance.

3. Structure of the project

Introduction: problem, aim, novelty and importance.
Literature analysis: literature analysis related to aircraft maintenance organizations, aircraft maintenance, waste management processes and Lean manufacturing concept.
Methodology: optimization goal formation, considerable data collection, management methods overview.
Research part: interview analysis and process, optimization function formulation, case scenario modelling.
Results and recommendations: insights related to a case study of efficient waste sorting and implementation of Lean manufacturing in aircraft maintenance organization.

4. Requirements and conditions
5. This task assignment is an integral part of the final project
6. Project submission deadline: 2016 May 20.

Given to the student: Matas Valenitnavičius

Task Assignment received: Matas Valenitnavičius

Supervisor: Assoc. Prof. dr. Kęstutis Pilkauskas

Valentinavičius Matas. WASTE SORTING OPTIMIZATION IN AIRCRAFT MAINTENANCE: IMPLEMENTATION OF LEAN MANAGEMENT. *Master's* thesis supervisor doc. Kęstutis Pilkauskas. The Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study area and field: Industrial Management and Engineering, Technological Sciences

Keywords: aviation, Lean, manufacturing, waste, sorting, management.

Kaunas, 2016. 06 p.

SUMMARY

The main problem posed for aircraft maintenance waste sorting management is current absence of effective waste management strategy. To achieve better overall profit and processes efficiency, innovations in managing production waste has to be made. This adds to overall improvement of waste sorting efficiency that leads to more environmentally friendly manufacturing.

The first chapter is devoted to cutting-edge analysis which describe current management peculiarities and problems in aircraft maintenance and repair organizations around the globe, the special attention is given to Lithuanian companies.

The second section provides universal solution for waste management problems by introducing Lean management methods in aircraft maintenance hangar environment. Identification of determinant characteristics: time, distance, type and quantity of waste generated during manufacturing processes. Modelling case scenarios and selecting best solution.

The third section looks at the economic objectives of the assessment, prices of equipment, optimization costs. In addition, Lean implementation costs are introduced.

Master's thesis consists of three parts: literature review, methodology and research. The explanatory note consists of introduction, the managerial level of analysis, modelling scenarios, conclusions, references and appendices. Graphical part of explanatory part consists of the 28 illustrations and 17 drawing tables. Appendices consists of 16 general tables.

Matas Valentinavičius. ATLIEKŲ RŪŠIAVIMO OPTIMIZAVIMAS ORLAIVIŲ TECHNINIO APTARNAVIMO PROCESE: LEAN GAMYBOS DIEGIMAS. *Magistro* baigiamasis projektas / vadovas doc. dr. Kęstutis Pilkauskas; Kauno technologijos universitetas, Mechanikos Inžinerijos ir Dizaino fakultetas.

Studijų kryptis ir sritis: Pramonės Inžinerija ir Vadyba, Technologijos mokslai.

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Kaunas, 2016. 06 p.

SANTRAUKA

Pagrindinė problema lėktuvo servise yra atliekų šalinimo nebuvimas. Kad pasiekti geriausią našumą, naujovės valdymo strategijoje turi būti įdiegtos. Visa tai padės atliekų rūšiavimo našumui ir aplinkos apsaugai.

Pirma darbo dalis yra skirta valdymo analizei ir lėktuvo išlaikymui bei servisui visame pasaulyje. Ypatingas dėmesys skiriamas Lietuvos įmonėms.

Antra darbo dalis pateikia bendrą sprendimo būdą atliekų šalinimui. Pagrindiniai terminai naudojami darbe: laikas, atstumas, atliekų tipas ir kiekis gamybos proceso etape. Geriausio sprendimo pasirinkimas taip pat apžvelgiamas darbe. Trečia skiltis apžvelgia ekonomines problemas, įrangos, viso proceso kainas. Papildomai yra apskaičiuojamas Lean valdymo sistemos diegimo kaštai.

Magistro darbas susideda iš trijų dalių: literatūros apžvalgos, metodinės dalies ir brėžinių. Teorinė dalis susideda iš įvado, vadybinės analizės ir scenarijų modeliavimo dalies, išvadų, šaltinų sąrašo ir priedų. Grafinė darbo dalis susideda iš 28 iliustracijų ir 17 lentelių. Priedų grafinė dalis susideda iš 16 lentelių.

CONTENTS

CONTENT OF TABLES

CONTENT OF FIGURES

INTRODUCTION

The world's demand of aviation services is rapidly growing and the technology of management of resources is in great importance to create cost effective ways to maintain the high quality and safety of air transport. This paper is orientated to big markets, particularly to aircraft maintenance service suppliers. These service providers have to act flexibly and efficiently to meet customer demands. To achieve the efficiency required, new solutions to manufacturing processes have to be applied. Every step in managing aircraft technical support is important so that all work flow could operate without disruption and be planned overhead every time.

After literature overview the conclusion can be drawn that no studies about waste management in aircraft maintenance organisations that implemented Lean philosophy to optimize waste sorting have been done. In order to understand this concept, its long-term viability, and its application within the aerospace MRO sector fully, this paper presents the adoption of Lean within the MRO industry by carrying out a research and optimization waste sorting processes.

For this day a new perspective to the big market competitiveness is needed [1]. There are two main types of competing aircraft maintenance/repair organisations(MRO). First one is orientated to maintaining small airline fleets and engage in big long-term difficult maintenance checks, that require a lot of labour time to complete. These companies build up in countries that provide advantage of low-paid workforce, geographical location diversity – Eastern Europe, South America and Southeast Asia regions, also plays as advantage [2]. The biggest problems these companies meet is lack of management and dedication of employees, – what leads to low efficiency, long delays, loses in processes. The second type of competition are companies that are placed in highly developed countries located in Western Europe, North America regions. Advanced cultural relations and time proved brands satisfy costumers that manage bigger fleets and has higher demand in on time services. These bigger and more advanced companies had time and resources to acquire great experience by gathering information and implementing it to improve their management systems. According to study of Marais and Robichaud, 36% of fines and legal actions to MRO involve inadequate maintenance, with recent years showing a decline to about 20%, which reflects continuation of improvement of maintenance practices [3].

For now, these big businesses offer high quality, time efficient, but relatively high cost services. Regarding this information, it is important to determine the competitive advantage maximization strategies of the small MRO's. The main problem of this topic is smaller MRO's management of waste sorting and implementation of Lean manufacturing. According to recent study of Ayeni and Bayns The increasing need for maintenance, repair, and overhaul (MRO) organizations to meet customers' demands in quality and reduced lead times is key to its survival within the aviation industry [4]. Furthermore, with the unpredictability in the global market and difficultieswith forecasting characteristic of the MRO industry there is an increased need for the re-evaluation of the operation models of organizations within this sector. However, severe economic turmoil and ever-increasing global competition introduce the opportunity for the adoption of a resilient, tried, and tested business operation model such as Lean [4]. In order to understand this concept, its long-term viability, and its application within the aerospace MRO sector fully, this paper presents the state-of-the-art in terms of the adoption of Lean within the MRO industry by carrying out a systematic review of the literature.

This paper establishes the common perception of Lean by the MRO industry and the measurable progress that has been made on the subject. Some issues and challenges are also highlighted including the misconceptions that arise from the direct transference of the perception of Lean from other industrial sectors into the aerospace MRO industry. The enablers and inhibitors' of Lean within the aviation industry are also discussed. This paper exposes the scarcity of the literature and the general lagging behind of the industry to the adoption of the Lean paradigm.

Aim: Evaluate and decide efficient waste sorting solution and implement Lean manufacturing methods on aircraft maintenance.

Tasks:

1. analyse waste management peculiarities;
2. overview the concept of Lean manufacturing;
3. overview current waste management system in "FL technics" aircraft maintenance and repair organization, gather information about aircraft maintenance hangar environment, waste migration, quantity and type;
4. conduct case studies and decide the most effective way of waste sorting;
5. apply Lean philosophy on over all waste management system.

1. LITERATURE REVIEW

1.1. Analysis of aircraft MRO

For analysis of aircraft maintenance, implication of MRO has to be concluded. Maintenance repair and operations (MRO) or maintenance, repair, and overhaul involves fixing any sort of mechanical, plumbing or electrical device should it become out of order or broken (known as repair, unscheduled, or casualty maintenance) [25].

1.1.1. Commercial aircraft maintenance organizations

Commercial aircraft maintenance, repair and overhaul (MRO) is an essential requirement to ensure that aircraft are maintained in pre-determined conditions of airworthiness to safely transport passengers and cargo [5]. The commercial aircraft MRO market is influenced by external factors in the wider air transport industry including global fleet size, aircraft utilisation and increasing and decreasing air traffic volumes for both passengers and cargo.

The commercial aircraft MRO market has fluctuated in recent years with the recent economic challenges and downturn in demand reflected in trends of falling revenue for a number of leading MRO companies. More recently, the aviation industry has indicated signs of recovery with considerable growing demand forecast over the next decade in regions such as the Asia-Pacific and Middle East. This is expected to act as one of the key market drivers for the commercial aircraft MRO sector in the short to medium term future.

The top 20 aircraft maintenence organizations:

- AAR Corporation
- Air China Technic / Ameco Beijing
- Air France Industries KLM Engineering & Maintenance
- Airbus
- Boeing Company
- British Airways Engineering
- Delta TechOps
- Fokker Technologies
- GE Aviation
- Hong Kong Aircraft Engineering Co. Ltd
- Iberia Maintenance
- Lufthansa Technik
- MTU Maintenance
- Rolls Royce Holdings PLC

- SIA Engineering Company
- SR Technics
- ST Aerospace
- TAP Maintenance & Engineering
- Turkish Technic
- United Technologies Corporation [6].

1.1.2. Aircraft maintenance

Aircraft MRO mainly performs a preventitive type of maintenance. Maintenance can be translated as the overhaul, repair, inspection or modification of an aircraft or aircraft component. Main activities are devided to two basic niches: Base and Line maintenance.

Base maintenance works are concentrated to all special maintenance checks needed to comply with aircraft manufacturers, EASA/FAA and costumers requirements and reglutions for issuing airworthy airplanes to service. All performance taken in base maintenance often takes a long period of time. Tasks are heavy, performed in closed – hangar environment, seasonality prevails in base maintenance [3].

Line maintenance works specializes in short pre-flight checks that is neccesary to be done in airports, often in outdoor conditions. Includes such tasks as ensuring compliance with Airworthiness Directives or Service Bulletins.

1.1.3. Aircraft maintenence checks

Aircraft maintenance checks are periodic inspections that have to be done on all commercial/civil aircraft after a certain amount of time or usage. Military aircraft normally follow specific maintenance programmes which may or may not be similar to those of commercial/civil operators. Airlines and other commercial operators of large or turbine-powered aircraft follow a continuous inspection program approved by the Federal Aviation Administration (FAA) in the United States [1], or by other airworthiness authorities such as Transport Canada or the European Aviation Safety Agency (EASA). Under FAA oversight, each operator prepares a Continuous Airworthiness Maintenance Program (CAMP) under its Operations Specifications or "OpSpecs" [2], The CAMP includes both routine and detailed inspections. Airlines and airworthiness authorities casually refer to the detailed inspections as "checks", commonly one of the following: A check, B check, C check, or D check. A and B checks are lighter checks, while C and D are considered heavier checks.

1.2. Analysis of waste management in airports and MRO

The aviation industry worldwide has a reputation for being a major polluter. Ways in which airports address the issue of the environment are examining both the problems and the strategies adopted in disposal. To establish in depth review overall airport recycling/waste minimization, waste management in aircraft MRO and airplane economic life topic are discussed.

1.2.1. Overall airport Recycling/Waste Minimization

A successful long-term airport recycling program is the result of careful planning, precise execution, and continual testing and improvement. Using examples from the experiences of airports around the country, along with input from the Environmental Protection Agency (EPA) [23], ten primary steps have been identified to design and implement an effective airport recycling/waste minimization program. While the problem of effective recycling/waste minimization at airports is universal, each airport faces a unique set of problems depending on its individual region, unique geography and society. Therefore, while some general practices are applicable to all airports, some solutions discussed may only apply to a particular airport or region [7].

1.2.2. Waste management in aircraft MRO

Waste management in aircraft maintenance and repair organizations have a lot of simularities to other management system that are used in vechicle, ship, submarine, military equipment manufacturing processes. Mostly it depends of the size of manufacture/maintenance facility manufacturing capacity. Facilities that create high output of waste materials tend to use inside logistics to lower the costs of total maintenance process [22]. These companies deliver allready recycled or sorted materials to waste collecting institutions. In this thesis we are concentrated of finding the best waste sorting solution to factories in this, bigger capacity producers sector.

Every time when low capacity of waste is generated manufacturer chooses the most cost–effective way which is selling untreated unsorted wasted materials to other companies that have more experience in managing higher accumulations of waste products. This management way characterizes features of small MRO.

Generaly waste in MRO is generated in aircraft maintenance hangars: in the hangars, aircraft are subjected to the repairs and maintenance that are necessary for the safety and smooth operation of such large, complex pieces of machinery. In addition, airlines have aircraft ground service equipment (GSE) that need to be serviced as well. Servicing equipment results in a number of predictable types of waste, such as oil, grease, certain hazardous chemicals, universal waste (batteries, electronics, light bulbs), wastewater, plastic and vehicle waste such as tires and fluids (brake, transmission, etc.). These hangars also typically have office space where office waste is generated [8].

Waste sorting optimization in maintenance proccess can be performed after analysis of waste types generated during maintenance and repair processes. Researches can be conducted by listing general types of waste materials and produced quantities.

1.2.3. Generated waste types

1. Hazardous waste (Oxydizer)
2. Liquid waste (hydraulic fluid, oil, jet fuel)
3. Recyclable waste (rubber, papper)
4. Mixed waste (papper/plastics)
5. Toxic waste (Paint, primer)

General types of waste are consumable materials and structure materials.

Consumable materials are generated by performing removal/installation, inspection, cleaning and applying anticorosion additives or painting materials unto the aircraft component or fusalage surfaces.

1.2.4. Quantity of consumables wasted

Disposal of used Aircrafts, their structural components. With some 1000 heavy airliners in need of disposal each year and modern planes being made from compounds instead of just aluminum, there is a need for more research and communication between the recycling and aviation industries [1]. Until now, the bigger parts of aircrafts were produced with aluminum, but a modern Boeing 787 or Airbus A350 XWB is now made of compounds.

Materials used during manufacturing include short and long carbon fiber composites, textiles and carpet, landing gears, electronic devices, titanium and steel alloys and other parts. For these compounds, recycling processes are not yet implemented or available. Also, there is a lack of markets buying these recycled resources [2]. Structure waste are generated by conducting repairs of metal and composite aircraft structure components.

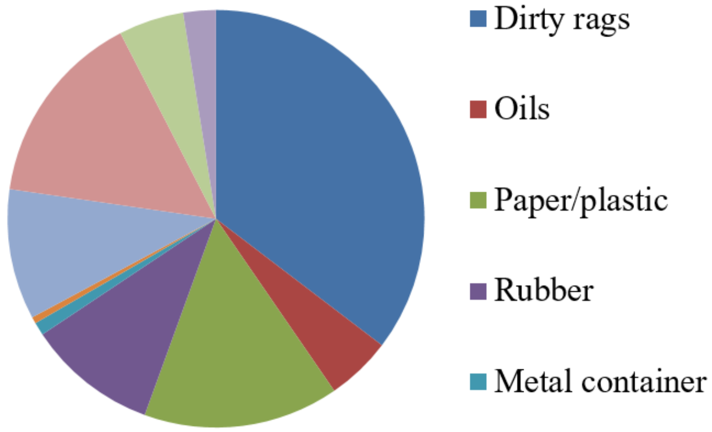

Figure 1.2.1 Consumables wasted

1.2.5. Quantity of structure parts wasted

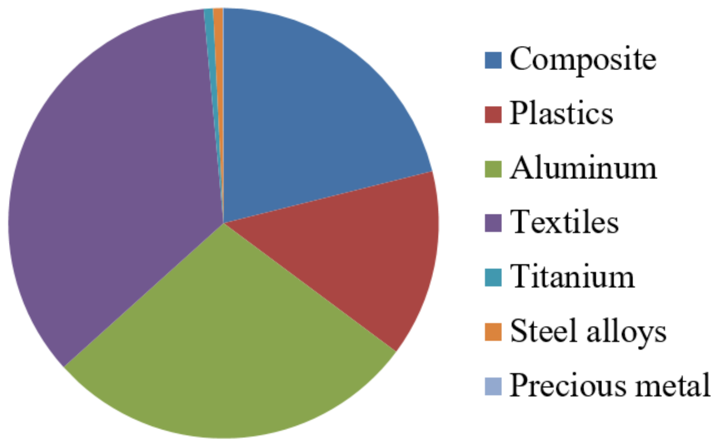

Figure 1.2.2 Structure wasted

1.2.5. Example of waste management in MRO from western Europe

Example of waste sorting from "Lufthansa Technics" base maintenance base in Shannon, Ireland represents how waste can be managed by using multiple, different purpose, small volume waste bins that are located in every work zone. Waste bins are attached to variety of equipment like steps, tables and etc. that are assigned to precise zone. Every day engineers have to collect accumulated waste from work zone waste bins (marked as circles in Fig. 1.1.). and bring them to general waste disposal.

This solution has an advantage of easier waste bin access and faster lead times during maintenance processes.

Disadvantages are that it is necessary to have placement spots for recycle bins what overloads work place, furthermore equipment for attaching waste bins cannot be moved to different work zones or be placed in other places of the hangar. For implementation of this method overall aircraft maintenance equipment have to be specialized for each zone what means that increased number of equipment have to be acquired.

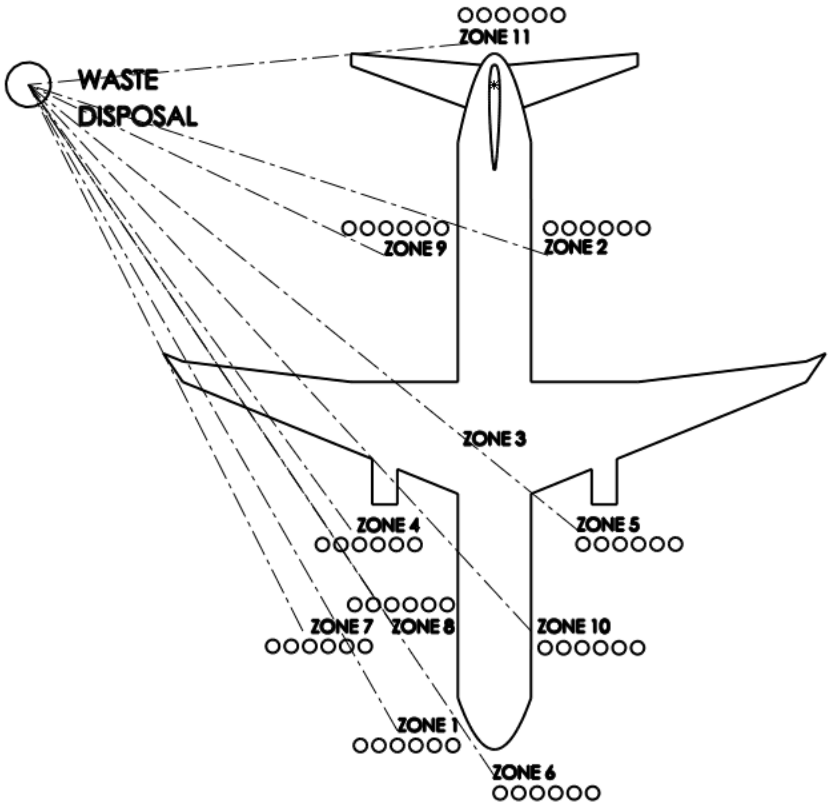

Figure 1.2.3 Example from "Lufthansa technics"

1.2.6. Airplane economic life

Estimates from the Aircraft Fleet Recycling Association are that over the next 20 years, 12,000 airplanes worth $1.3 trillion will come to the end of their service life. Currently 80-85% of an aircraft is recycled. AFRA aims to increase this number to 90% by the end of 2016 [16].

As aircraft life span increases more maintenance is needed to sustain it's working condition. In addition more waste is produced during these processes.

The field of aircraft recycling is developing very fast at the moment [17].

Averge age of aircraft is increasing so aircraft maintenance and waste generated during exploitation is also increasing.

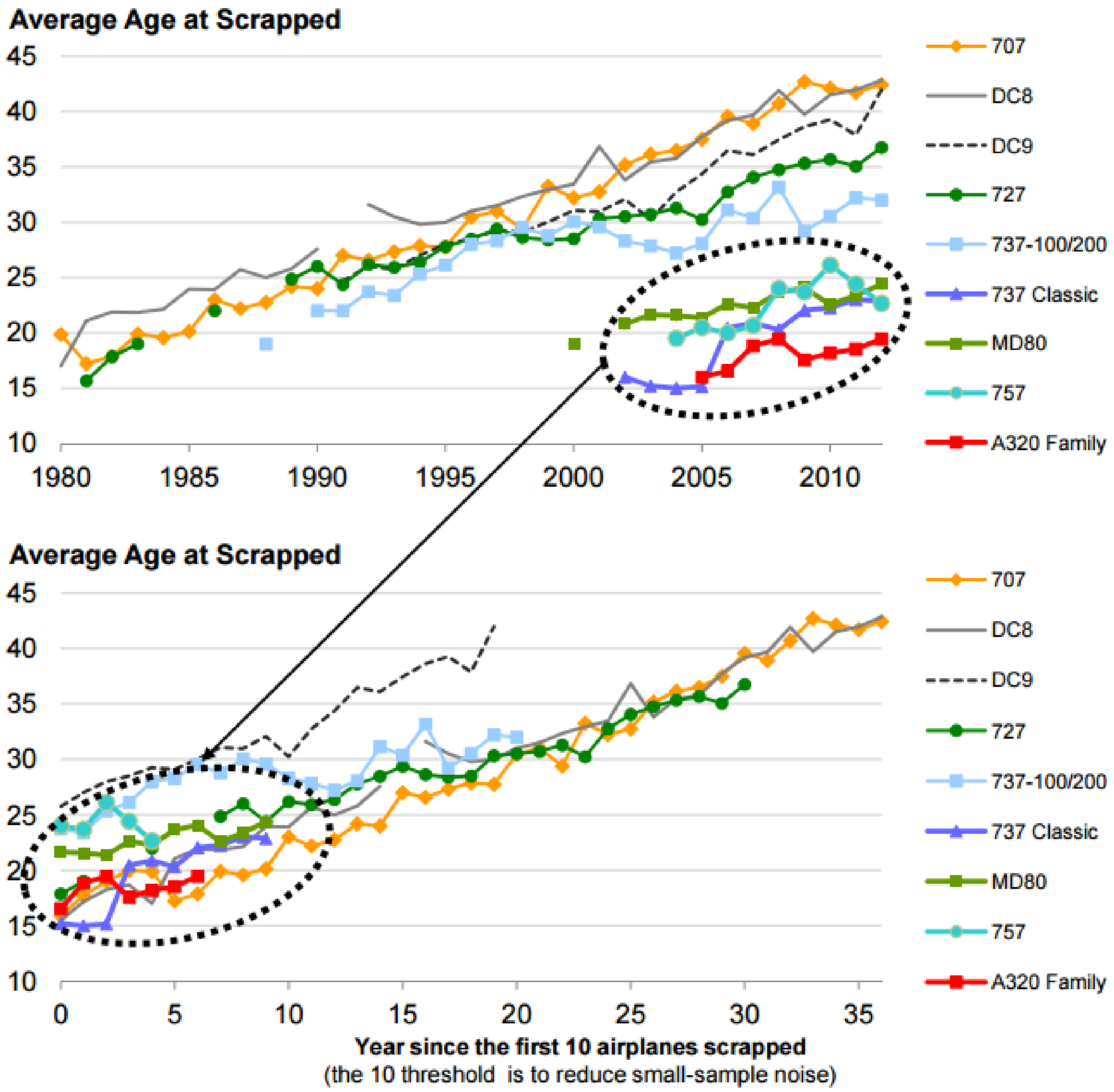

Figure 1.2.4 Aircraft age when scrapped increasement [3]

Table 1 shows the same set of data plotted against a relative time scale horizontal axis, where each aircraft program has its own clock, which starts to tick when the fleet starts to see steady retirements On this axis the data reveals that recent average fleet starts to see steady retirements. On this axis, the data reveals that recent average retirement ages of 737 Classics, MD80s, 757s, and A320s, in fact, follow the same trend as many previous models, suggesting no meaningful shift from what we have seen in prior generations [15].

1.3. Lean manufacturing

Lean manufacturing is a cornerstone of this thesis, all our objectives for improving waste management processes directly interact to main Lean principles. Lean in manufacturing was introduced by Henry Ford, for over the years general principles of Lean hasn't changed a lot, but as industries developed, this efficiency generating idea was shared and adapted in every advanced production company, this diversification of utilization leed to development of complex systems of management that are now baiscaly refer as Lean. General obrevation of lean: Lean manufacturing or lean production, often simply "Lean", is a systematic method for the elimination of waste ("Muda") within a manufacturing system. Lean also takes into account waste created through overburden ("Muri") and waste created through unevenness in work loads ("Mura") [4].

A key concept in Lean is Waste- anything that doesn't add value to the costumer. In Lean, there are 5 types of Waste we will use in our thesis:

Transport. It is all about unecessary movement or work, in our case every necesary movement during waste disposal from aircraft to waste disposal.

Inventory. Like holding unescesary information or materials for longer than required. Our waste disposal management system case scenarios are pu together on these principle, if we use less disposal sets, we save productive floor space, save money for equipment.

*Motion***.** The non-value-added movements of peaple. We try to shorten the distances between aircrafts work zones and waste sets.

Waiting. Couses delays or stoppages. In our scenarios waiting does big effect for aicraft maintenance procedures, because every time worker leaves the workplace to dispose of collected waste, he is no longer working and that as Lean pronaunces is Muda.

Over-processing. Unecessary activity due to complex processes and systems. Such as if there is not accurate location of specific type of waste bin the worker uses uneccesary movement to search correct items arround the hangar, so we look for ways making all bins collected to sets of bins and deployed in places easies to reach and use [9].

1.3.1. Manufacturing-Improvement Programs: Effective?

Despite significant investments in “lean manufacturing,” “Six Sigma,” and other productivity programs, most large manufacturers failed to reach—or even come close to—their cost savings targets over the last 12 months.

According to the AlixPartners Senior Executives Survey on the Effectiveness of Manufacturing-Improvement Programs [25], nearly 70% of manufacturing executives reported their manufacturing-improvement efforts led to a reduction in manufacturing costs of 4% or less—below the typical minimum threshold for successful productivity programs. Low Expectations, lower results, more than half (53%) of respondents cited an average targeted savings of 4% or less per year (as a percentage of total manufacturing costs), or did not have defined targets. Those that targeted more ambitious savings were more often than not disappointed.

What were the savings that manufacturing improvement efforts realized last year as a percentage of total manufacturing cost are displayed in figure 1.3.1.

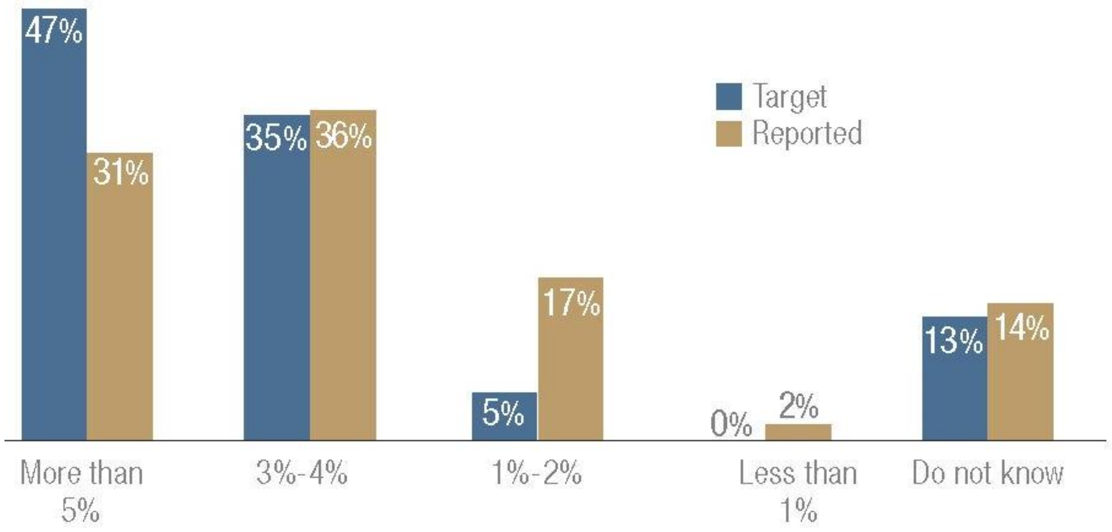

Figure 1.3.1 Targeted savings versus Realized savings [28]

The most common reasons when the project fails is visualized in figure 1.3.2. The most often met problem is that the project takes longer than expected, explonation of this phenomenon is simple, because there are not all variables counted in during evaluation of projects complete duration of implementation. Also these project are managed in very different companies were there are no specialized or very experienced specialists that are dealing with these kind of projects in every day bases, in other hand new project require for engagement from every employee that means that employee that had to perfom simple tasks have to break themselves to start on new thinking. Esspecialy in big companies were management is more complicated, personel is more divided and communications become indolent.

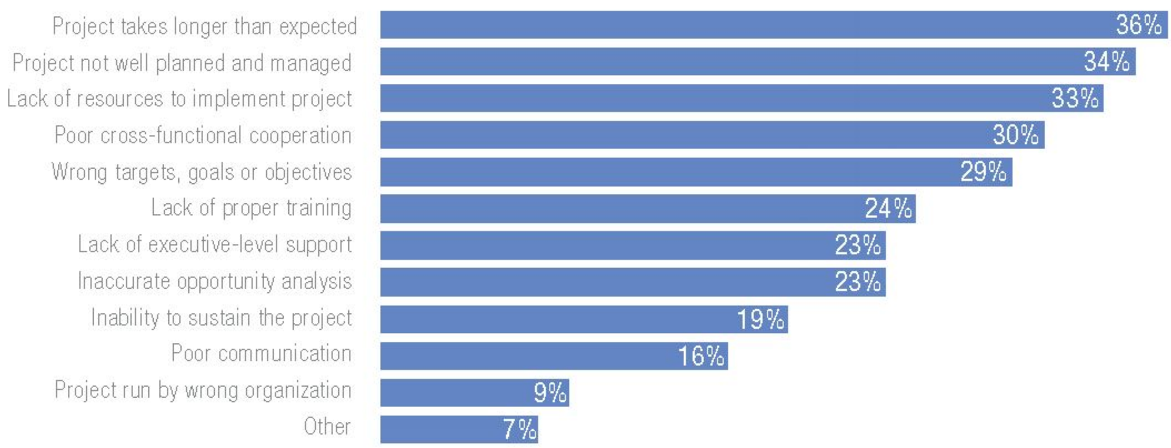

Figure 1.3.2 Program challenges [28]

2. METHODOLOGY

2.1. Lean, industrial use

2.1.1. Definition of DMAIC

There are two major approaches that have been reported in the literature for implementing Lean, the DMAIC (Define-Measure-Analysis- Improve Control) and the DMADV (Define- Measure-Analysis-Develop-Verify) [30], [31]. The DMAIC approach is recommended for analyzing and improving the existing product or process, while the DMADV approach is appropriate for designing new product or process. An exploratory six sigma case study conducted at the parent company based on the five phases of the methodology: Define, Measure, Analyze, Improve and Control (DMAIC) is described shortly. The DMAIC approach is described which was used to dig deeper into the non-conforming waste material received by the parent recycling company from analyzed maintenance organization. This exploratory case study was conducted within the aviation industry in order to examine the nature of the complex interactions between the two major constructs lean and work flow management in waste sorting at the company. Data was collected from maintenance hangar environment during aircraft maintenance processes on heavy maintenance. Waste flows from 11 work zones were precisely measured during 4-week period.

DMAIC Process:

1. Problem definition. Defining the problem is the most important step in Six-Sigma project since better understanding of the problem at this stage will help at the later stages of the project. In order to define the objectives of the project, maintenance company's claims were investigated. The management needed to resolve the problem of long process lead time.
2. Measuring the scope of problem During the measure phase, the various non-conformance issues with the incoming waste materials from the waste recycling company were identified also there were time loses believed are generating during waste disposal inside maintenance/repair processes. The top root causes were identified against the maintenance organizations management requirements and standards.
3. Analyze the causes After the first two phases of DMAIC approach, it was decided to focus on the improvement plan to reduce waste disposal time from workplace.
4. Improve the exiting processes. The improve phase consisted of several activities organized to address the nonconformance causing factors. Finding out week spots in work flows during waste disposal and eliminating them by implementing Lean ideas that enables to improve overall process efficiency.

5. Control. The control phase is the last stage for the DMAIC approach. A control plan has to be designed and introduced to the production. The plan provides a summary of the control application which aims to minimize the process variation and ensures reducement in lead times during maintenance processes. In addition, the control plans guarantee that the proposed process is used correctly.

2.2. Data collection

Waste production was observed every day and entries were made into table 3.1. The table construction enables to show quantity of waste were generated in relevant work zone at specific of week of the month, it also account type of waste. There were no questionaries applied for employess, all data for every human factor what is in effect during waste management processes we match to my own 3 years experience by directly encountering waste management problems in performance of aircraft maintenance assesments.

2.2.1. Analysis of work ground environment

For optimization of waste sorting the analysis of maintenance environment have to be performed. Evaluation subject:

1. Hangar employment loads
2. Layout of hangar workplace area

In Figure 2.4. crosslined area marks the work space perimeter were all maintenance equipment can be relocated and all material waste paths are. Dotted line markes perimeter arround the aircraft where no stationary equipment can be placed incase of aircrafts moving surfaces do not make contact and cause damage to them (Fig. 2.5).

2.2.2. Hangar employment loads

During peak of the working season five aircrafts are pulled to the hangar for one month maintenance checks, those aircrafts takes up hangar floor space in set order. For measuring of aircraft maintenance hangar employment loads Gantt chart – work schedule is used(Fig.2.3). Calculations during waste management optimization process will be done by assuming that maximum number of aircrafts that are visiting hangar at the selected time is five, except for scenarios that describe one aircraft. This exception is made for to reasearch the best waste bin set setting position arround the aircraft to reduce lead time in waste disposal. Furthermore these results could be used in configuration up to three aircrafts due to increase of space arround the aircraft work zones.

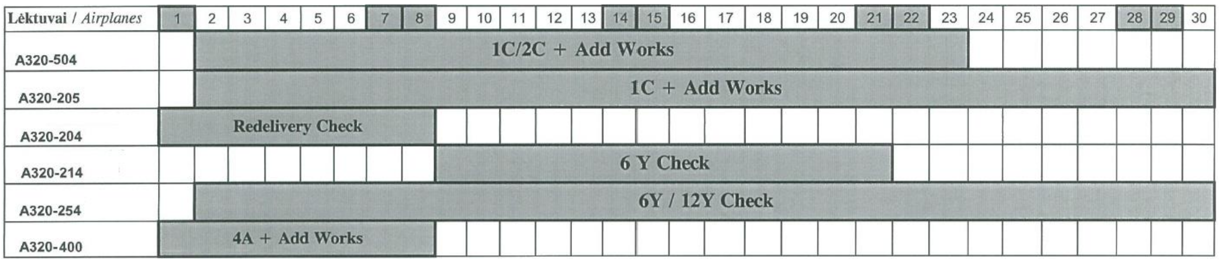

Figure 2.3 Hangar visit plan [27].

2.2.3. Definition of hangar workplace area

Aircraft positioning map is in Kaunas Airport aircraft maintenance hangar. Hangar area is 8000 squere meters. All case scenario modeling will be done in consider that aircraft are counted from left to right from up to lower sides of the hangar plan (Fig.2.4). Describtion of workplace is necessary to start modelling of waste roots and waste concentration in the work zones, it provides information to effectively implement bin typing and positioning. The specific model of workplace is needed to compose workplace scenario.

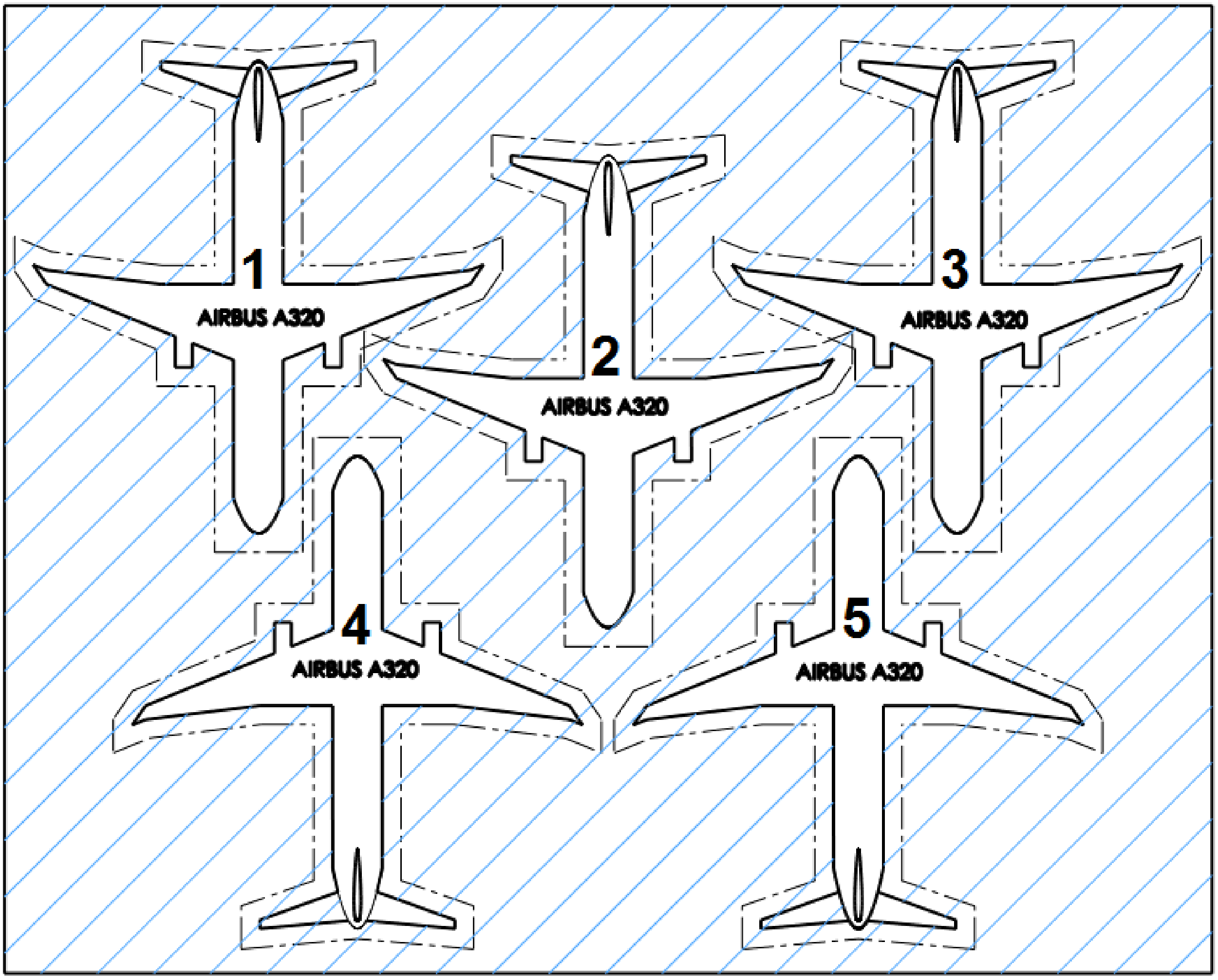

Figure 2.4 Hangar workplace plan

Conducting a selection of one aircraft that includes all maintenance zones to proceed it as current workplace.

2.2.4. Layout of workplace limitted access

In every zone's location there are specific types of equipment like steps, toll carts, tables and waste bins. All zones make up a workplace (Fig. 2.5).

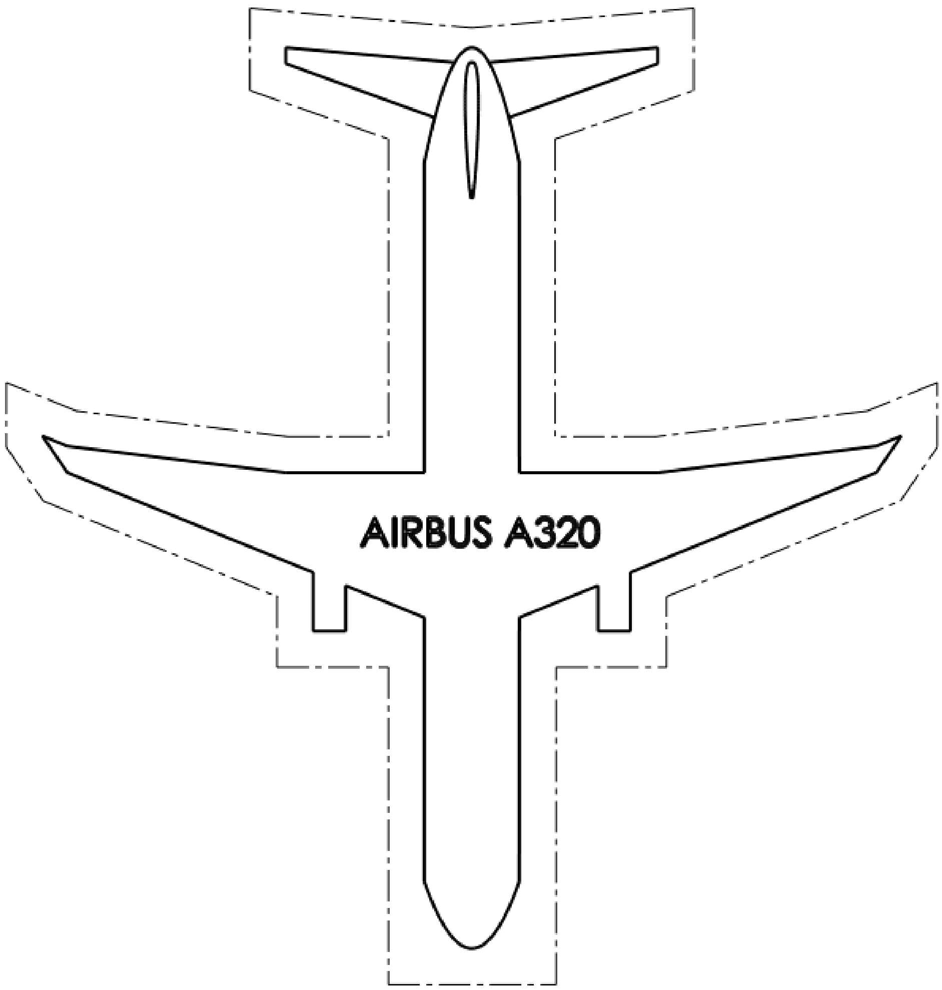

Figure 2.5 Workplace

2.2.5. Workplace division to zones

Workplace classification. Aircraft maintenance performance takes place in inner and outer parts of aircraft. To simplify approach all parts are divided into zones, there are 11 zones (Fig. 2.6).:

1. Cockpit
2. Landing gear
3. Wings
4. Right hand engine
5. Left hand engine
6. Nose compartment
7. Avionics compartment
8. Front cargo
9. Aft cargo
10. Passenger cabin
11. Tail section

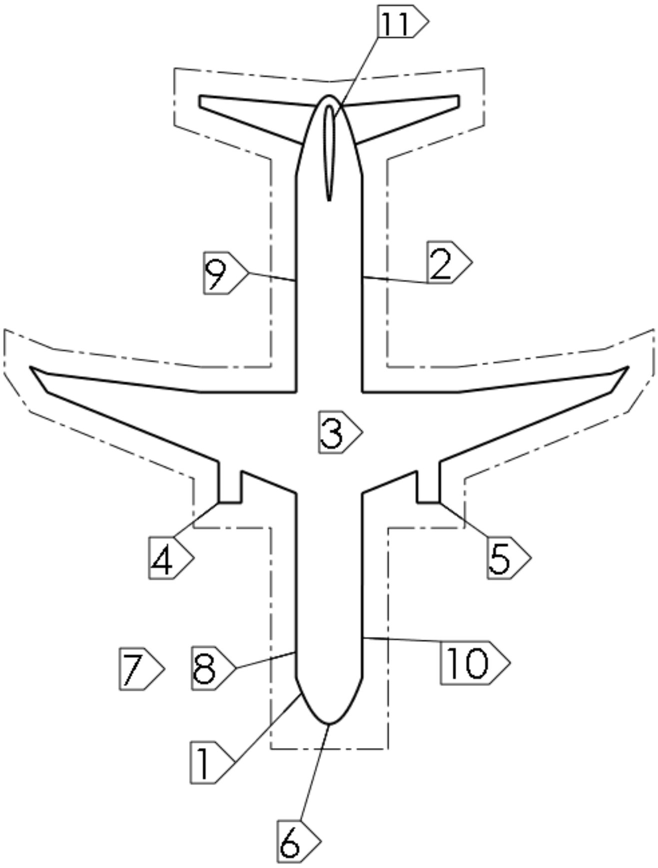

Figure 2.6 Zone plan

2.3. Waste sorting

2.3.1. Waste sorting costs

Waste sorting costs consists of these variables:

1. Types of waste are generated
2. Transportation between workplace and storage place
3. Storage costs for space and inventory
4. Recycling costs on disposal by selling

2.3.2. Types of waste are generated

There are two basic types of waste, these are liquid and solid ones, both of them can be hazardous. Hazardous waste types:

Toxic – can cause injury or death when inhaled, eaten, swallowed, or absorbed through the skin.

Flammable – can easily ignite and burn rapidly: inflammable means flammable.

Corrosive – can burn skin on contact and can eat away the surface of other materials.

Reactive – can react with air, water or other substances to produce toxic vapors or explosions.

Liquid and solid waste types can also be grouped into organic, re-usable and recyclable waste.

Most of hazardous waste collected during aircraft maintenance processes are dirty rags, oil filters, contaminated clothing, fuel filters, aerosol bottles, acetone liquids and all sorts of cleaning detergents.

2.3.3. Transportation between workplace and storage place

Transportation between workplace and storage place will be carried on by using wheeled waste bins or bin strollers, bin capacity and strollers configuration will be ajusted in further research of generated waste capacity during maintenance process.

2.3.4. Storage costs for space and inventory

The cost to store, hold or carry inventory consists of:

1. The cost of the space used including rent, heat, maintenance, etc.
2. The cost of the money tied up in inventory.
3. The cost of insurance and perhaps property tax.
4. The cost of deterioration and obsolescence of the inventory items.

Some of the storage costs are a function of the cost or value of the inventory, while some storage costs are dependent on the physical size of the items.

2.3.5. Recycling costs on disposal

Every company that deals with hazardous waste materials meets high waste disposal prices(Table 2), so to make shore being as much economical as possible we need to perform waste sorting in first hands, that means sorting waste has to be not less important goal for every employee. Sorting waste from the start of it's way to recycling company helps to achieve both economical and environment friendly solution.

Proper characterization is vital to the successful management of any waste, but it is a particularly important aspect of managing hazardous chemicals. Illustrated waste characterization helps minimize the risk of violations by properly identifying hazardous and non-hazardous material—including byproducts, chemicals, solvents, waste water and excess inventory.

Table 2.1 Hazardous waste disposal price list [18]

Waste type	Units	EUR/metric units excluding taxes
Filter materials, rags, safety clothing that are contaminated with hazardous materials	kg	0,72
Oil filters	kg	0,43
Air, fuel filters	kg	0,43

2.4. Waste management

2.4.1. Productivity management

Productivity management in waste sorting process consists of well planed waste transportation and collection logistics that can be planed after detail research of quantity, type, location of disposal, and overall waste sorting performance that is directly connected to emplyees working attitude. For the purpose of well organised waste management solution, LEAN implementation into the process is necessary.

To ensure the savings considered on time management, flow charts and time-motion studies need to be perforemed to gather information of process performance and optimise current processes to get best results. Time management connects sorting and costing to create reliable time saving waste disposal solution that stands on logical inventory marking, placement and employee LEAN working attitude.

2.4.2. Time-motion study

Time-motion efficiency study can be implicated in waste sorting operations by allowing faster and more precise waste sorting process. To find out the best way for solving this problem we need to research waste motion and timing in current workplace environment. For start we need to find current waste bin positions and mark them on hangar plan, also it would be necessary to include the type of waste is been disposed in selected bin. By implementing visual study research of types of waste, we need to find out time, quantity, frequency and distance that been handled every time employee has to take between aircraft and waste bin. This improvement can be done by correcting positions, labeling and other later seen factors.

2.4.3. Flow process charts

A flowchart is a type of diagram that represents an algorithm, workflow or process, showing the steps as boxes of various kinds, and their order by connecting them with arrows. This diagrammatic representation illustrates a solution model to a given problem. Flowcharts are used in analyzing, designing, documenting or managing a process or program in various fields [13].

In our case flow process chart will be used for finding and illustrating the process of waste separation during aircraft maintenance program. This chart will show where are the biggest time loses in inventory, transporting, would help to increase effectivity of overall waste sorting.

3. RESEARCH PART

3.1. Case study analysis

3.1.1. Definition of workplace

Workplace scenario is necessary to find waste roots and concentration in the area, it provides information to effectively implement bin typing and positioning. The specific model of workplace is needed to compose workplace scenario. In case there are 5 aircrafts in the hangar at one time we select one aircraft with all maintenance zones to proceed it as current workplace. Aircraft positioning map is in Kaunas Airport "FL Technics" aircraft base maintenance hangar (Fig. 1.).

3.1.2. Case study of currently used methods in selected MRO

The small MRO base in Kaunas airport manages waste by positioning waste disposal bins in positions market in Fig. 1. In current case there are five Airbus A320 aircrafts parked in the hangar. Parking positions are taken from hangar plan [21]. Waste disposal locations market by crosselined circkles are sets of six different types of bins that are 240l capacity each, there are one set in the upper and one in the lower position of the hangar. Employee can pull needed bin apart from the set and park it anywhere in the hangar. Each bin taken from the set is market by a white circle. In this case there are 8 bins which are separated from disposal sets.

1. According to these conditions we can descripe probability of waste which is generated in Zone 11 utilization to it's type belonging waste bin:

$$P = \frac{Z}{Y} \qquad (3.1.)$$

Y– Number of types of waste bins;

Z– Type of bin currently needed;

P– Probability to choose correct bin from first attempt.

Probabiliy to find the correct bin in first attempt is $\frac{1}{6}$, what enables us to calculate the worst case scenario, in this case for measurement of efficiency we use maximum timming of waste disposal- t_{max}, this scenario evaluates maximum time needed to pick up waste from aircraft Zone 11, bring it to disposal bin and come back to the work zone.

2. Time evaluation:

$$t_{max} = \frac{S_1 + S_2 + \cdots S_n}{V} \qquad (3.2)$$

n- distance number;

S_n– travel distances between bins;

t_{max}– maximum travel time;

V– average walking speed of man [24];

t_{max} is 106s.

3. Approximation of total time spent on waste disposal:

$$\mathrm{AT} = \mathrm{NA} \cdot WN \cdot \sum F \div NW \cdot WL \quad (3.3)$$

NA – number of aircraft;

WN – number of work zones;

D – disposal time;

F – frequency;

WL – work load (weeks/year);

NW – number of waste bins in one set;

AT – total time.

Result. In this case 3330,48 hours have been spent only on waste disposal during waste maintenance practices.

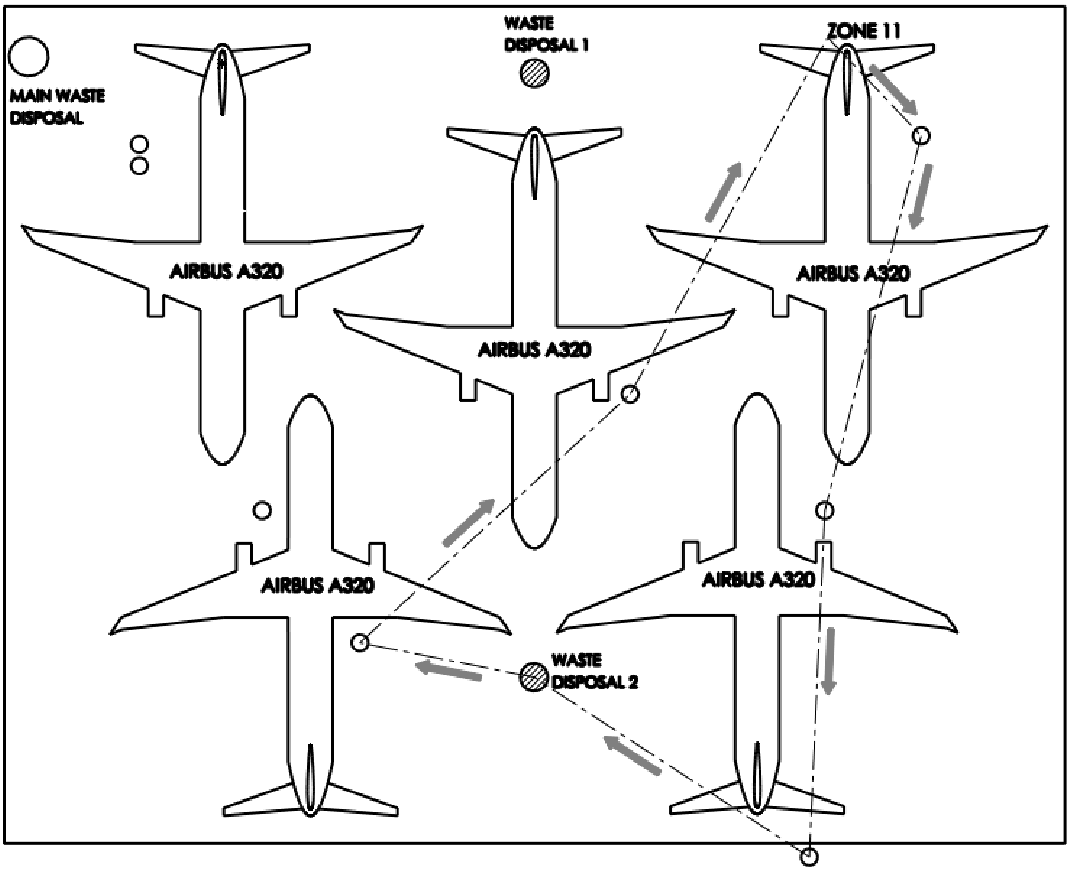

Figure 3.1 Waste flow network visualization

3.2. Modeling loads

3.2.1. Waste loads in work zones

Modeling waste loads in work zones is necessary to conduct further decision of inventory, inventory placing, recycling costs and transportation. To get the most realistic results we have to choose correct timing when we have to check waste collection in the waste bins. Waste generation is directly connected to maintenance plans. In this case we took on situation when one month(4 weeks) maintenance check is performed. We choose this 4 week period because it is mostly common time interval that aircraft spends in maintenance. Quantities of maintenance waste every week and on average is recorded in table 1[14].

After waste sorting analysis, all data about quantity, time of collection, type of waste products and collection sites, and temperature requirements was systemized in the 3.1 table.

Table. 3.1 waste loads in work zones[17]

	Work zone	Type of waste	Qty/week 1 (ℓ)	Qty/week 2 (ℓ)	Qty/week 3 (ℓ)	Qty/week 4 (ℓ)	Qty/week average (ℓ)
1	Cockpit	Paper/plastic	1	0	10	25	9
		Dirty rags	10	10	12	5	9,25
		Used filters	0	0	0	0	0,0
		Metal	0,5	0,5	0	0,5	0,38
		Rubber	7	5	5	3	5
		Chemicals	0	0	1	1	0,5
2	Landing gear	Paper/plastic	5	1	1	40	11,75
		Dirty rags	32	20	5	7	16
		Used filters	0	0	0	0	0
		Metal	0,5	0	0	0	0,13
		Rubber	15	5	2	2	6
		Chemicals	0,5	0,5	0,5	0,5	0,5
3	Wings	Paper/plastic	1	5	20	55	20,25
		Dirty rags	10	70	7	10	24,25
		Used filters	0	0,5	0	0	0,13
		Metal	0,5	0,5	0	0,5	0,38
		Rubber	10	5	5	7	6,75
		Chemicals	2	0,5	0,5	1	1

4	Right hand engine	Paper/plastic	0	0,5	12	2	3,63
		Dirty rags	10	12	7	5	8,5
		Used filters	0,5	1	0	0	0,38
		Metal	0,5	0,5	0	0,5	0,38
		Rubber	7	5	5	2	4,75
		Chemicals	5	2	1	0	2
5	Left hand engine	Paper/plastic	0	1	10	12	5,75
		Dirty rags	11	10	7	2	7,5
		Used filters	0,5	1	0	0	0,38
		Metal	0	0,5	1	0	0,38
		Rubber	7	5	5	2	4,75
		Chemicals	5	2	1	0	2
6	Avionics compartm-ent	Paper/plastic	2	3	5	10	5
		Dirty rags	3	2	1	1	1,75
		Used filters	0	0	0	0	0,0
		Metal	0,5	0	0	0	0,13
		Rubber	3	3	1	3	2,5
		Chemicals	0,5	0,5	0,5	0,5	0,5
7	Front cargo	Paper/plastic	0	2	3	4	2,25
		Dirty rags	12	10	7	5	8,5
		Used filters	0	0	0	0	0,0
		Metal	0,2	0	0	0	0,05
		Rubber	3	0	0	5	2
		Chemicals	1	1	1	0	0,75
8	Aft cargo	Paper/plastic	0,5	2	2	4	2,13
		Dirty rags	10	20	10	5	11,25
		Used filters	0	2	0	0	0,5
		Metal	0,1	0,1	0,1	0	0,08
		Rubber	3	3	2	2	2,5
		Chemicals	0,5	0,5	1	0	0,5
9	Passenger cabin	Paper/plastic	0,2	0,1	12	15	6,83
		Dirty rags	24	5	4	20	13,25
		Used filters	0	0,5	0	0	0,13
		Metal	1	0	1	0,01	0,5

		Rubber	7	2	1	1	2,75
		Chemicals	0	0	0,5	0,5	0,25
10	Tail section	Paper/plastic	5	2	2	0,5	2,38
		Dirty rags	5	7	5	10	6,75
		Used filters	0	0	0	0	0,0
		Metal	0	0,5	0	0,01	0,13
		Rubber	6	3	3	5	4,25
		Chemicals	0	0	0,5	0,5	0,25
11	Nose compartment	Paper/plastic	0	2	2	0,5	1,13
		Dirty rags	3	1	1	1	1,5
		Used filters	0	0	0	0	0,0
		Metal	0	0,5	0	0,01	0,13
		Rubber	3	3	3	0	2,25
		Chemicals	0	0	0	0	0,0
Total			235	239,7	186,6	276,53	234,46

This study is made to analyse waste management pecularities in selected aircraft maintenance company and find the way to minimize time and inventory costs by also obtaining advancement in waste sorting efficiency.

The main data was collected throug observations of waste production, tables of waste flows were formed from one heavy maintenance check. This data collection was conducted during November 1st, 2nd, 3rd and 4th week, year 2015. The chaotic layout of garbage cans was the same, at least until this year, May, 2016. This has been confirmed by continiously tracking of situation by paying visits to studied environment.

3.3. Optimization process

For calculation of operating distances we need to specify workplace and main waste bin locations. These points are recovered during the research of workplace scenarios. Operating distance is walking distance employee has to take in workplace due to remove wasted materials from the aircraft and distance the waste operator needs to travel in the hangar taking the waste cart to the main waste bin.

Operating distance:

1. Aircraft to waste bin. The distance is carried ou by employee (mechanic/engineer) working in current work zone in internal or external parts of aircraft. Distance is measured on hangar map view using CAD programe „Solidworks“, distances is approximated to straight lines, walking

speed taken as 2,88 km/h.. [15]. Every distance is multiplied by 2 assmuning every time employee need to get back to the work place.

D – distance

TT – travel time

ES – Employees walking speed (0,8 m/s = 2.88km/h)

$$TT = D \cdot ES \quad (3.4)$$

2. Workplace to main waste bin. The distance is carried out by employee who is responible for ground service equimpment(GSE), Distance is measured on hangar map view, distances is approximated to straight lines, emlpoyee moves a bin or a stroller of bins (Fig 3.2.), walking speed taken as 2 km/h (speed is limited according to accesive load).
3. Desiding frequency of disposal. For one trip from work zone to waste set we assume that 0,5L of waste will be removed. So from general

   FV – frequency of visits

   WW – waste generated in zone per week

   QT – quantity of waste is carried per a time

$$\mathrm{F}V = \frac{WW}{QT} \quad (3.5)$$

4. Finding total time of waste disposal in current waste sorting scenario per year. In conditions that maximum work load is 24 weeks per year – due to industry nature seasonality applies.

   AT – total time (hours);

   WL – work load (weeks/year)

$$AT = \sum TT \cdot WL \div 3600 \quad (3.6)$$

Figure 3.2 Waste bin stroller [29]

3.4. Waste logistics network modelling

To conduct waste logistics network modelling in MRO hangar the analysis of case scenarios has to performed. Each case scenario is modelled in accordance with Kaunas MRO hangar plan, all drawings are up to scale 1:420.

3.4.1. Description of case scenarios

Figure 3.2. Illustrates the optimal solution of the aircraft maintenance waste disposal logistics. It involves aircraft work zones, waste disposal sets (6 types of waste bins in the same spot) general hangar waste disposal and recycling plant.

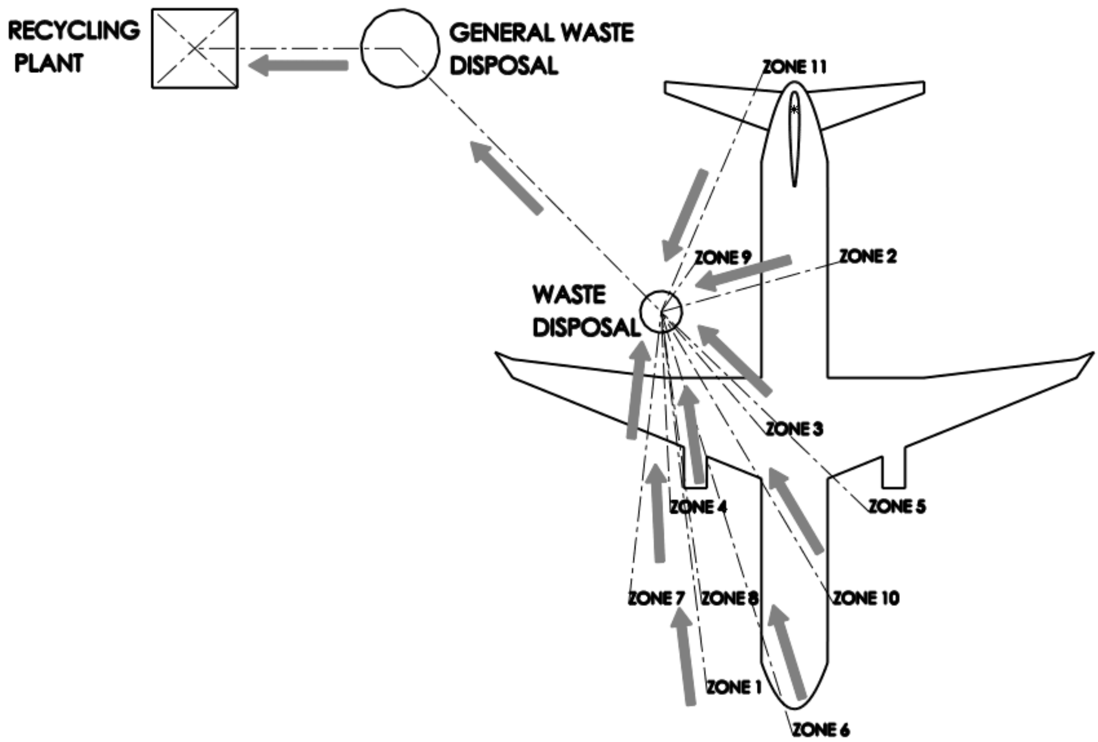

Figure 3.3 Waste flow network visualization

Case scenarios for each waste sorting optimization solution is made to resolve the advantageous or disadvantageous waste set positioning locations and number of them should be placed:

Case scenario 1. Solution 2, five aircrafts, one waste set. Case scenario is generated for evaluation of waste flows in case there is only one waste disposal in hangar that is located in upper left corner of hangar plan. From figure 3.3. It is visible that every waste path distance in comparison with other scenarios that we will discuss later is the longest. According to results all waste disposal time for a month would be 89,9 hours and overall capacity of waste bins should be selected are shown below in Table 3.2. For full waste quantity, distance and timming details see appendix No. 5 and 6.

Table. 3.2 Scenario 1, solution 2, five aircrafts, 3 waste sets. Results.

Type of waste	Bin capacity (l)	Total time of disposal (hours/week)
Paper/plastic	340	89,9
Dirty rags	770	
Used filters	60	
Metal	60	
Rubber	240	
Chemicals	80	

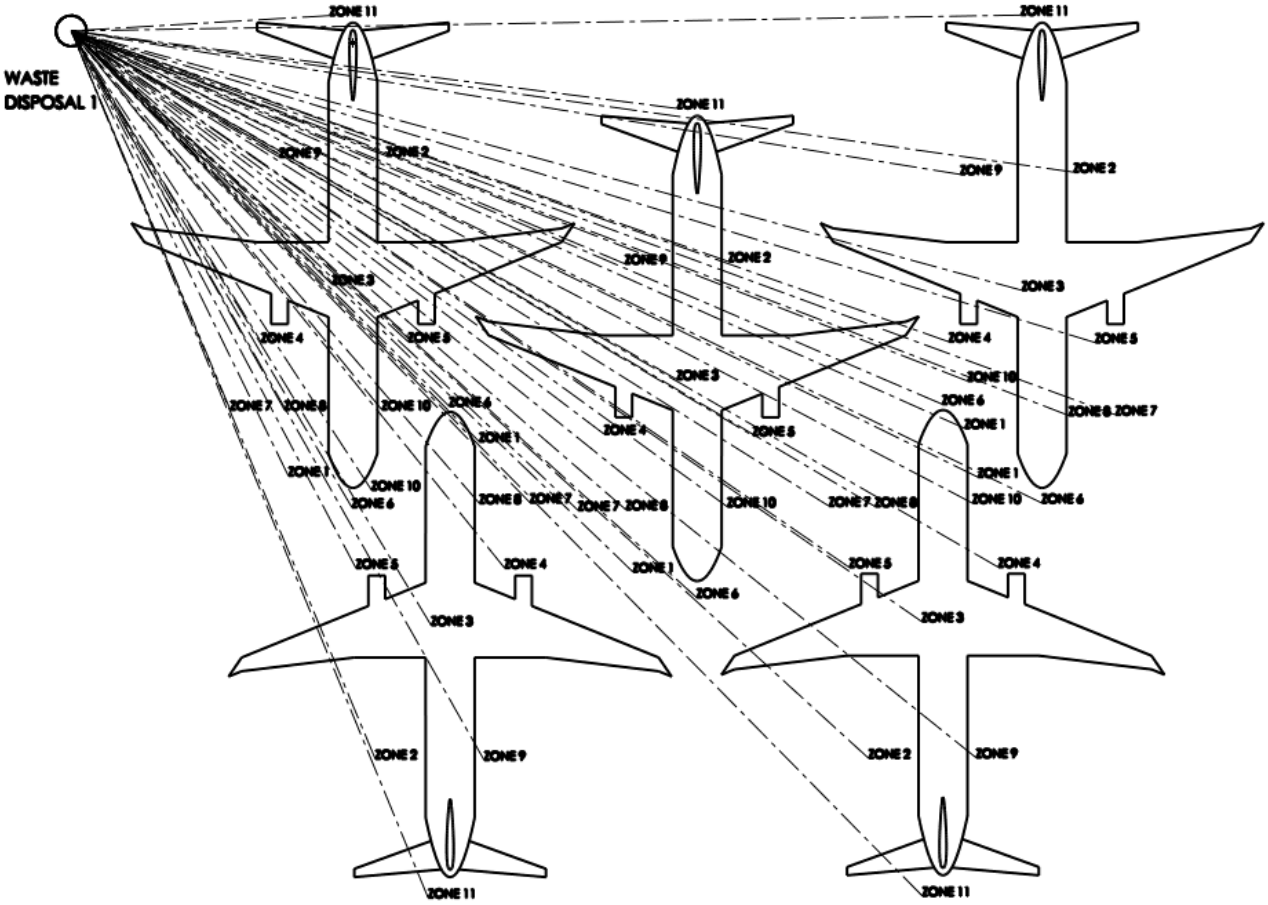

Figure 3.4 Scenario 1: Solution 3 – five aircrafts, one waste set

Case scenario 2. Solution 3 – one aircraft, one waste bin set. Case scenario is generated for evaluation of waste flows in case there is one waste disposal set in front, left hand section of an aircraft, this solution is excseptionally modelled for one aircraft at the time and can be adjusted for up to three aircrafts. From figure 3.4. According to results overall waste disposal time for a month would be 21,9 hours and overall capacity of waste bins should be selected are shown below in Table 3.3. For full waste quantity, distance and timming details see appendix No. 15 and 16.

Table 3.3 Scenario 2. Solution 3 – one aircraft, one waste bin set. Results

Type of waste	Bin capacity (l)	Total time of disposal (hours/week)
Paper/plastic	140	21,9
Dirty rags	140	
Used filters	60	
Metal	60	
Rubber	80	
Chemicals	60	

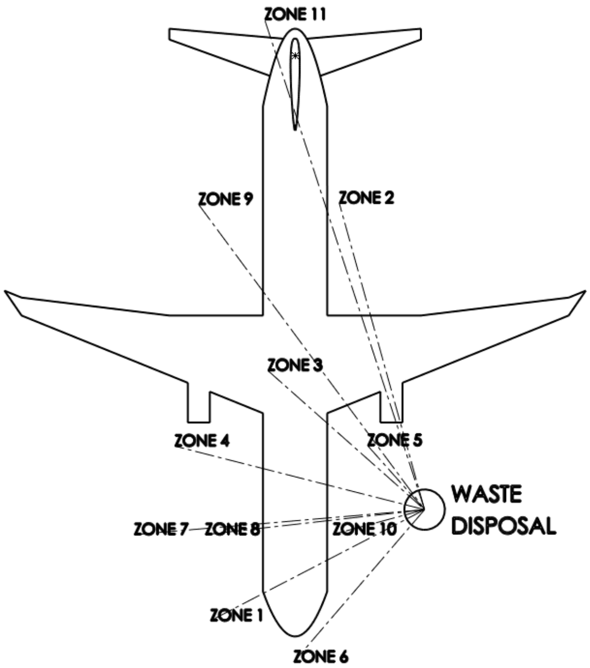

Figure 3.5 Scenario 2. Solution 3 – one aircraft, one waste bin set

Case scenario 2. Solution 1 – one aircraft, one waste bin set. Case scenario is generated for evaluation of waste flows in case there is one waste disposal set in aft, right hand, section of an aircraft, this solution is excseptionally modelled for one aircraft at the time and can be used for up to three aircrafts. From figure 3.5. dotted lines indicate waste paths. According to results all waste disposal time for a month would be 19,7 hours and overall capacity of waste bins should be selected are shown below in Table 3.4. For full waste quantity, distance and timming details see appendix No. 13 and 14.

Table 3.4 Scenario 2. Solution 1 – one aircraft, one waste bin set. Results

Type of waste	Bin capacity (l)	Total time of disposal (seconds/week)
Paper/plastic	120	19,9
Dirty rags	140	
Used filters	60	
Metal	60	
Rubber	80	
Chemicals	60	

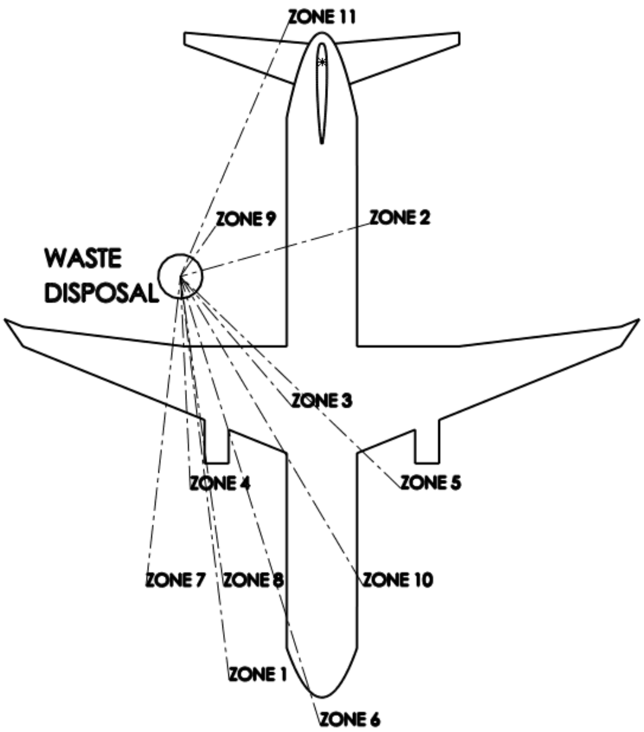

Figure 3.6 Scenario 2. Solution 1 – one aircraft, one waste bin set

Case scenario 1. Solution 2, five aircrafts, five waste sets. Case scenario for evaluation o waste flows in case there is five waste disposal sets in hangar that are located in Figure 3.4. and Figure 3.5. positions arround the aricraft. From figure 3.6. dotted lines indicate waste paths According to results all waste disposal time for a month would be 20,58 hours and overall capacity of waste bins should be selected are calculated from *Case scenario 2. Solution 1 – one aircraft, one waste bin set* results and *Case scenario 2. Solution 3 – one aircraft, one waste bin set* results, distance and timming details see appendix No. 14, 15, 16 and 17.

$$Scenario\ 1. Solution\ 2 = 3 \cdot \frac{Case\ scenario\ 2. Solution\ 1}{5} + 2 \cdot \frac{Case\ scenario\ 2. Solution\ 3}{5} \quad (1.1.)$$

$$Scenario\ 1. Solution\ 2 = 3 \cdot \frac{21,9}{5} + 2 \cdot \frac{19,7}{5} = 20,58\ hours$$

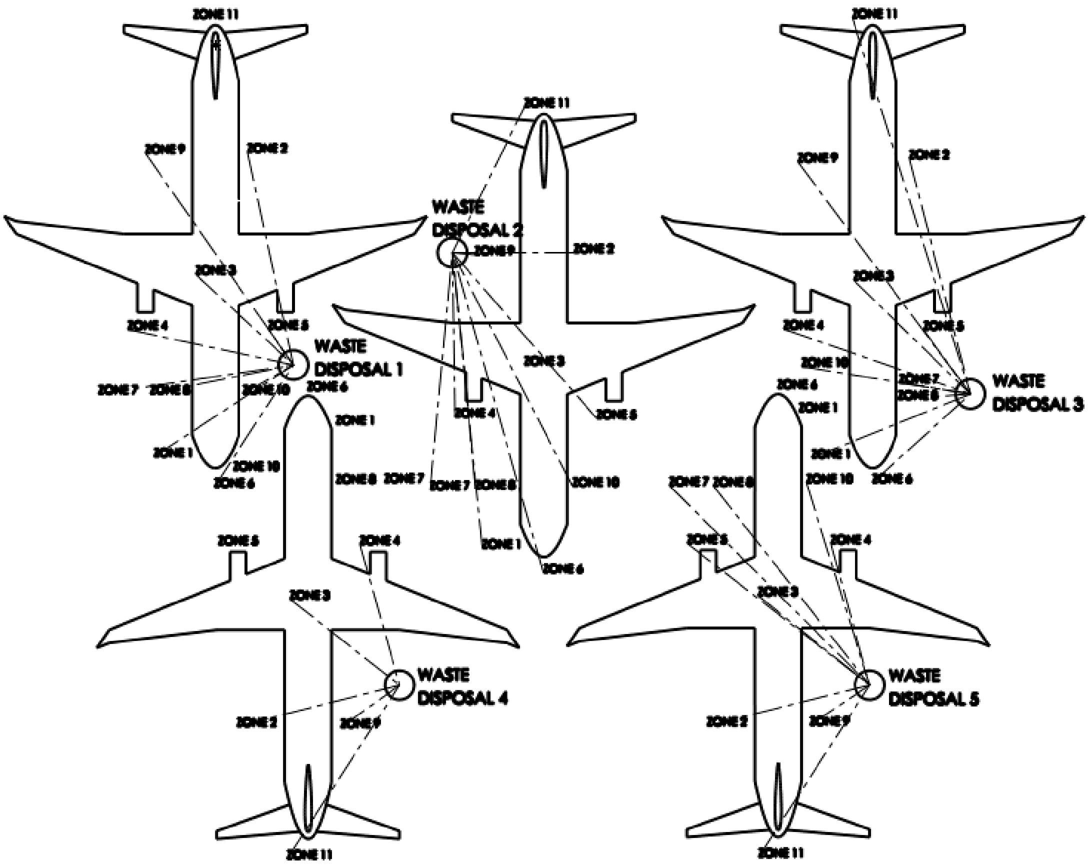

Figure 3.7 Scenario 1- solution 2, one aircrafts, one waste set

Case scenario 2. Solution 2 – five aircrafts, five waste bin sets. Case scenario for evaluation of waste flows in case there is five waste disposal sets placed in same formation as in *Scenario 1- solution 2*, but from figure 3.7. It is visible that every waste path trajectory is desided to be led to nearest waste disposal set, what makes more realistic simulation of employees desidion ability to look for shorter passage. According to results all waste disposal time for a month would be 19,86 hours and overall capacity of waste bins should be selected are shown bellow in table 3.5. For full waste quantity, distance and timming details see appendix No. 11 and 12.

Table 3.5 Scenario 2. Solution 2 – five aircrafts, five waste bin sets. Results

Set	Type of waste	Bin capacity (l)	Total time of disposal (hours/week)
1	Paper/plastic	120	19,86
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
2	Paper/plastics	120	
	Dirty rags	120	
	Used filters	60	
	Metal	60	
	Rubber	60	
	Chemicals	60	
3	Paper/plastic	140	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	
4	Paper/plastics	120	
	Dirty rags	140	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	
5	Paper/plastics	80	
	Dirty rags	120	
	Used filters	60	
	Metal	60	
	Rubber	60	
	Chemicals	60	

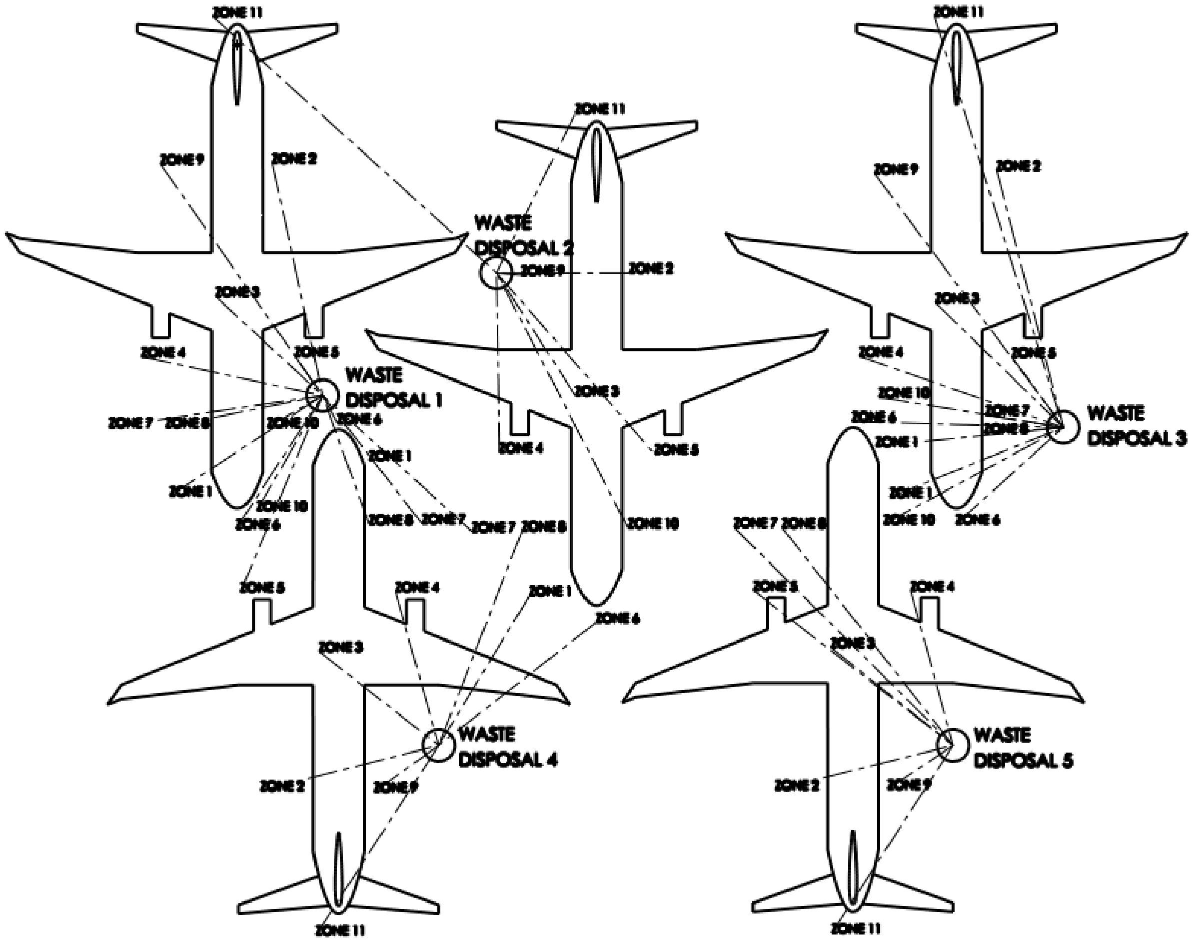

Figure 3.8 Scenario 2. Solution 2 – five aircrafts, five waste bin sets

Case scenario 3. Solution 2 – five aircrafts, four waste bin sets. Case scenario is generated for evaluation of waste flows in case there is four waste disposal sets in hangar that are located in horizontal center line of a hangar plan. From figure 3.8. Is visible all waste flows that are market in dotted line. This scenario helps to save equimpment costs and hangar floor space in comparison with case of *Scenario 2. Solution 2*. According to results all waste disposal time for a month would be 25,92 hours and overall capacity of waste bins should be selected are shown in table 3.6. For full waste quantity, distance and timming details see appendix No. 4.

Table 3.6 Scenario 3. Solution 2 – five aircrafts, four waste bin sets. Results

Set	**Type of waste**	**Bin capacity (l)**	**Total time of disposal (hours /week)**
1	Paper/plastic	120	25,9
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	
2	Paper/plastics	120	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
3	Paper/plastics	140	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
4	Paper/plastics	80	
	Dirty rags	140	
	Used filters	60	
	Metal	60	
	Rubber	60	
	Chemicals	60	

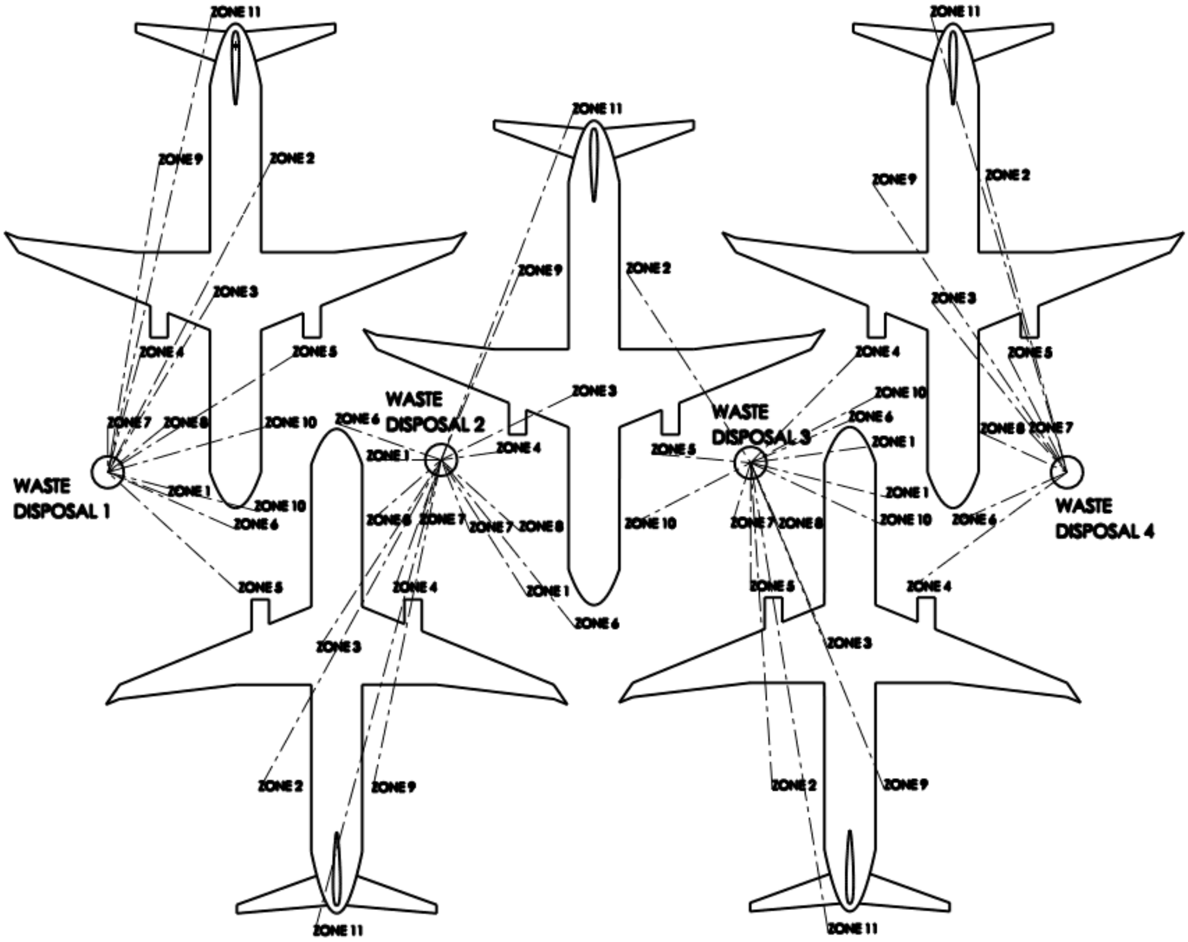

Figure 3.9 Scenario 3. Solution 2 – five aircrafts, four waste bin sets

Case scenario 3. Solution 1 – five aircrafts, four waste bin sets. Case scenario is generated for evaluation of waste flows in case there is four waste disposal sets in hangar that are located in four most likely to be seen and reached locations. From figure 3.9. Is visible all waste flows that are market in dotted line. This scenario helps to save equimpment costs and hangar floor space in comparison with case of *Scenario 2. Solution 2*. According to results all waste disposal time for a month would be 25,2 hours and overall capacity of waste bins should be selected are shown in table 3.7. For full waste quantity, distance and timming details see appendix No. 7 and 8.

Table 3.7 Scenario 3. Solution 1 – five aircrafts, four waste bin sets. Results

Set	Type of waste	Bin capacity (l)	Total time of disposal (hours/week)
1	Paper/plastic	140	25,2
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
2	Paper/plastics	140	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	
3	Paper/plastic	120	
	Dirty rags	140	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	
4	Paper/plastics	120	
	Dirty rags	140	
	Used filters	60	
	Metal	60	
	Rubber	80	
	Chemicals	60	

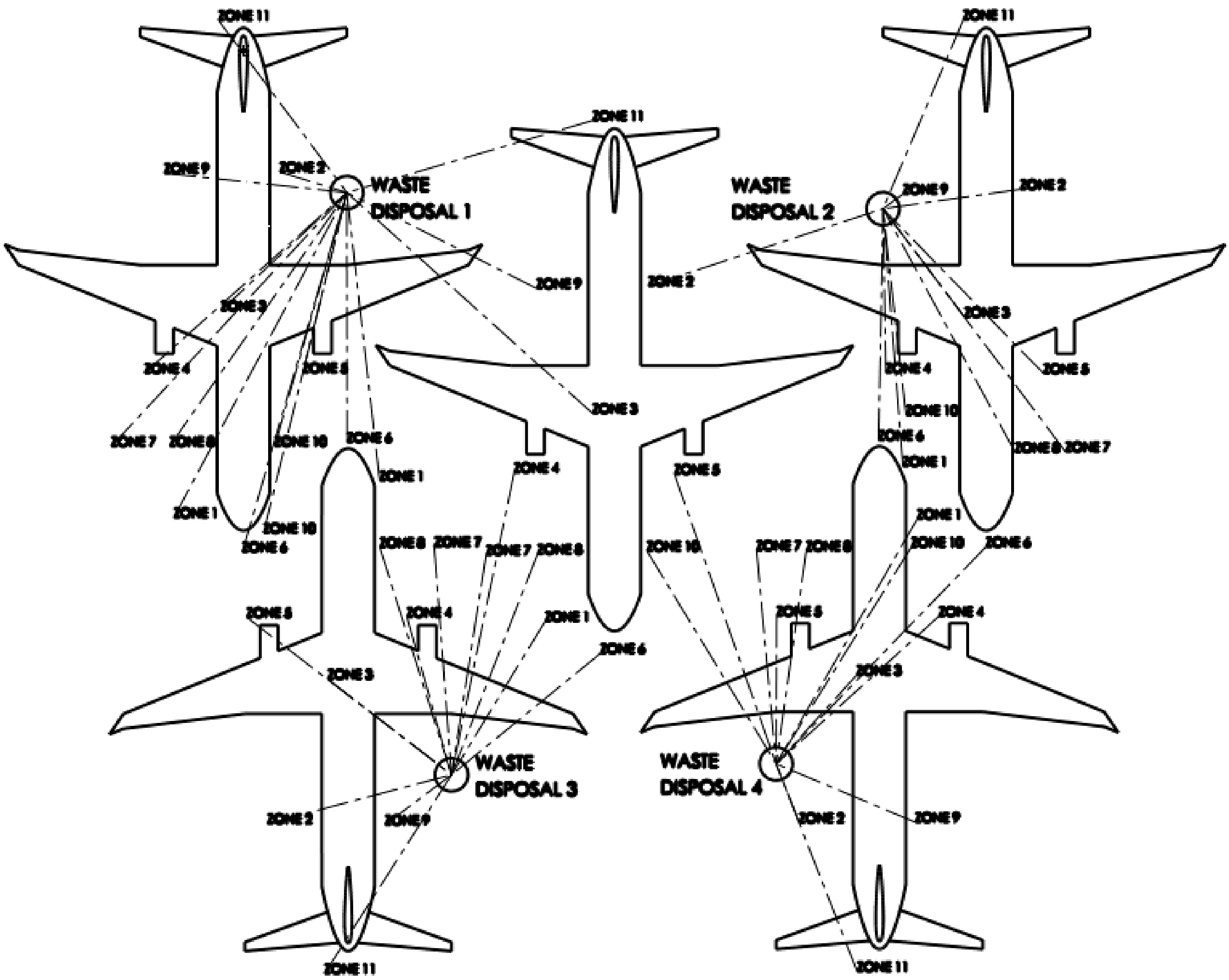

Figure 3.10 Scenario 3. Solution 1 – five aircrafts, four waste bin sets

Case scenario 1: Solution 1 – five Aircrafts, three waste bin sets. Case scenario is generated for evaluation of waste flows in case there is three waste disposal sets in hangar that are located in four most likely to be seen and approached locations. From figure 3.10. Is visible all waste flows that are market in dotted line. This scenario helps to save equimpment costs and hangar floor space in comparison with case of *Scenario 3. Solution 1* even bigger difference in number of bin sets appears in comparison with *Scenario 2. Solution 2*. According to results all waste disposal time for a month would be 28,03 hours and overall capacity of waste bins should be selected are shown in table 3.8. Big increase in labour hours is observed(19,86<28,3 hours) due to removing two waste bin sets. For full waste quantity, distance and timming details see appendix No. 1.

Table 3.8 Scenario 1. Solution 1 – five Aircrafts, three waste bin sets. Results

Set	Type of waste	Bin capacity (l)	Total time of disposal (hours/week)
1	Paper/plastic	140	28,03
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
2	Paper/plastics	240	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
3	Paper/plastics	240	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	

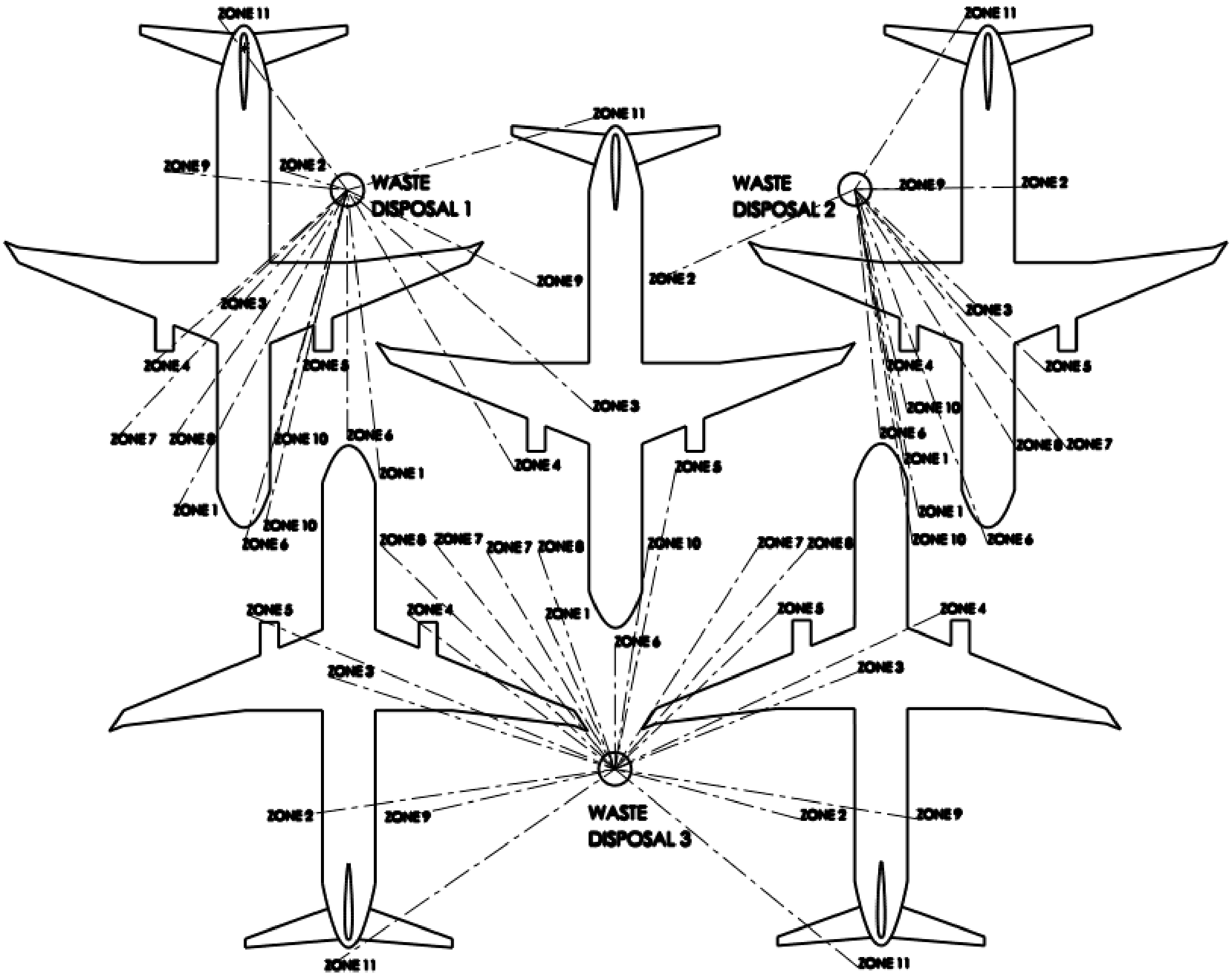

Figure 3.11 Scenario 1. Solution 1 – five Aircrafts, three waste bin sets

Case scenario 1. Solution 2 – five aircrafts, three waste bin sets. . Case scenario is generated for evaluation of waste flows in case there is three waste disposal sets in hangar that are located in four most likely to be seen and approached locations. From figure 3.10. Is visible all waste flows that are market in dotted line. This scenario helps to save equimpment costs and hangar floor space in comparison with case of *Scenario 3. Solution 1* even bigger difference in number of bin sets appears in comparison with *Scenario 2. Solution 2*. According to results all waste disposal time for a month would be 24,21 hours and overall capacity of waste bins should be selected are shown in table 3.8. For full waste quantity, distance and timming details see appendix No. 1. No. 3.

Table 3.9 Scenario 1: Solution 2 – five aircrafts, three waste bin sets. Results

Set	**Type of waste**	**Bin capacity (l)**	**Total time of disposal (hours/week)**
1	Paper/plastic	240	24,21
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
2	Paper/plastics	140	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	
3	Paper/plastic	140	
	Dirty rags	240	
	Used filters	60	
	Metal	60	
	Rubber	120	
	Chemicals	60	

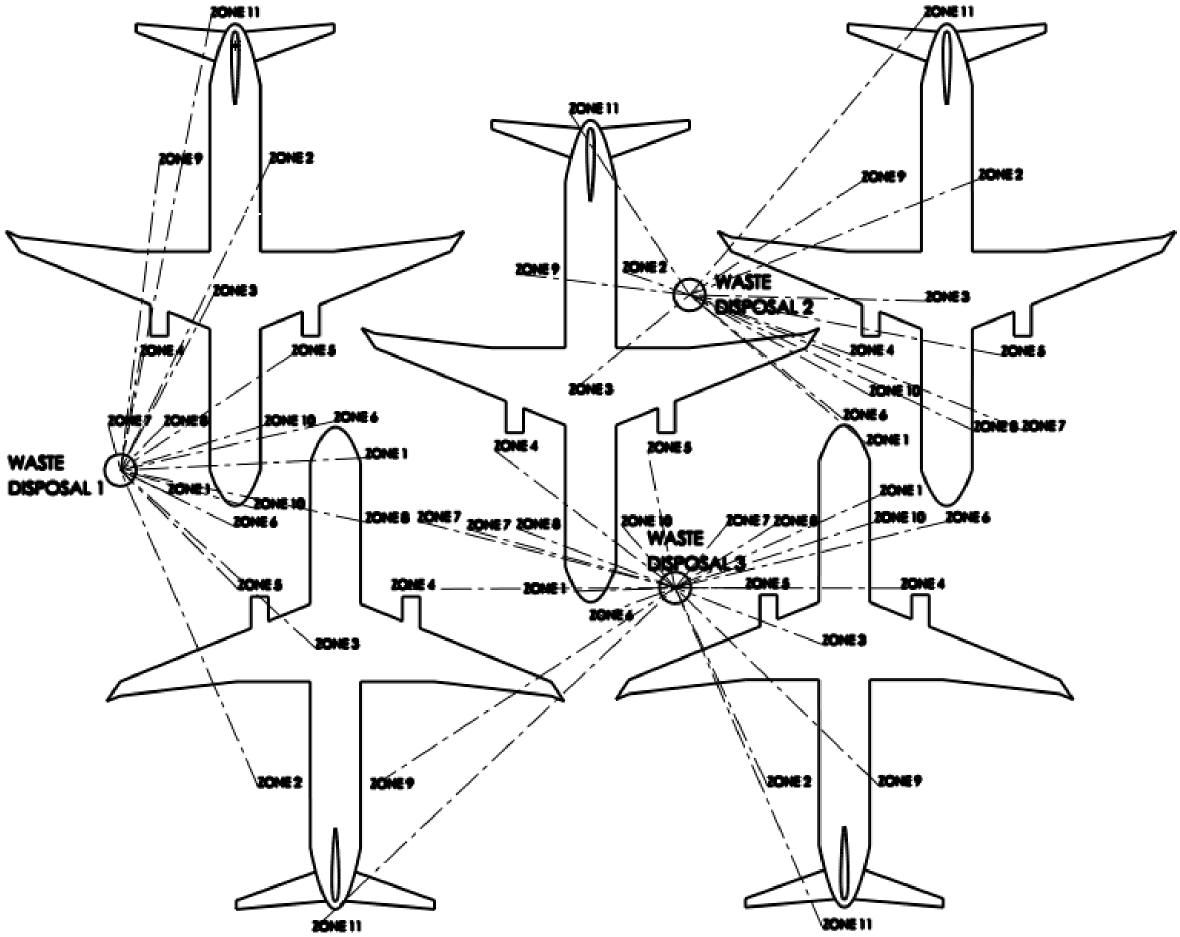

Figure 3.12 Scenario 1. Solution 2 – five aircrafts, three waste bin sets

Results. After case study analysis we can conclude that the most time efficient way of positioning waste bin sets is *„Case scenario 3. Solution 2 – five aircrafts, four waste bin sets"* – 19.86 hours/week.

3.5. Choosing inventory

After gathering results from modeling workloads in workstations we could decide the type of inventory we would use. In our case inventory is waste storage bins and bin strollers. Bins would be stacked to strollers and be treated as bin packs, bin back is a pack of different sorts of bins. Bins can be different volume and different labeling according to type of waste is used for. Stroller is a wheeled platform with waste bin positioning spots incorporated to make bin transportation from workplace to main recycle bin easier and faster. For every workplace there has to be a stroller of bins for certain type of waste collection. Every bin has to be fit for quantity of waste produced, and strollers has to be precise size to fit each configuration of bin sets.

Evaluation of waste bin sizes are made from overall volume o waste that are brought to the waste set see tables graph „total bin capacity" and „choosen bin capacity" (appendixes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16.), for every waste bin it was assumed to leave 25 liters of additional space in addition if unplaned waste flow accures.

3.6. Lean manufacturing implementation

3.6.1. Modelling Lean visual workplace

In a visual workplace, visual detailings are positioned at the point of use, giving employees immediate access to the information they need. Visuals can easily be understood at a glance, eliminating the wasted downtime that had previously been spent searching, asking, or waiting for information. Information placed on work place floor or equipment is helping for the employee to stay on focus, eliminates neccessary body movements. This model can greatly improve productivity, increase attention on specific tasks, awares of dangers and mistakes that is possible to happen while performing tasks.

For modeling visual workplace, optimized waste sorting set location scenario solution is choosen. In Figure 3.7. the „*Scenario 1- solution 2, five aircraft, five waste sets*“ main waste disposal site is connected with dotted line to appreciate waste flow direction that completes the hangar disposal rote(not marked on actual floor).

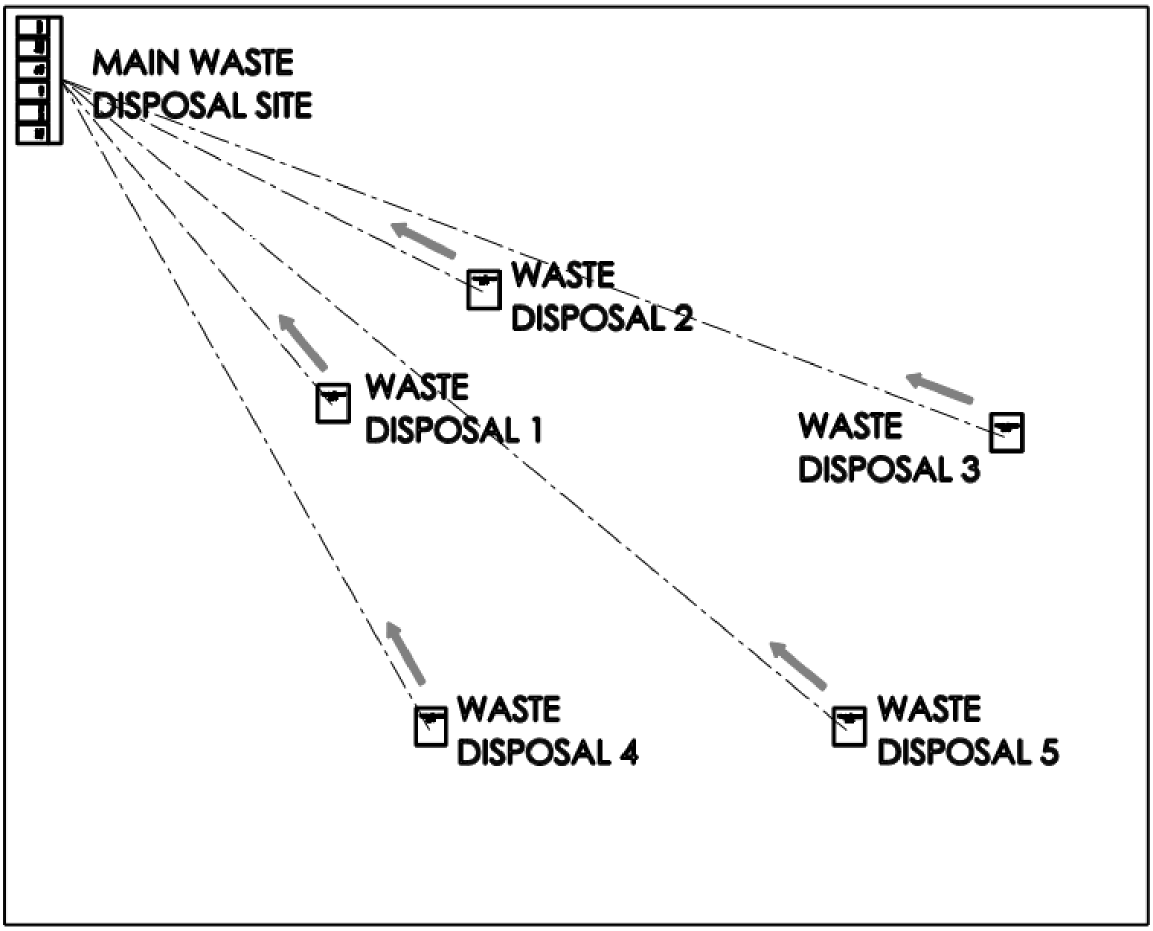

Figure 3.13 Waste set possitioning in hangar perimeter

In Figure 3.13 five waste disposal sets and one main waste disposal site is marked, for every site where waste disposal equipment is positioned there is floor marking. Adding visual detailings on hangar floor for each set and main waste disposal site will form types of floor markings: coloured line for filled areas with equipment and braked line that define perimeter where it should be free of any objects on the floor for easy access. These lines are 10 centimeters wide and painted in yellow colour.

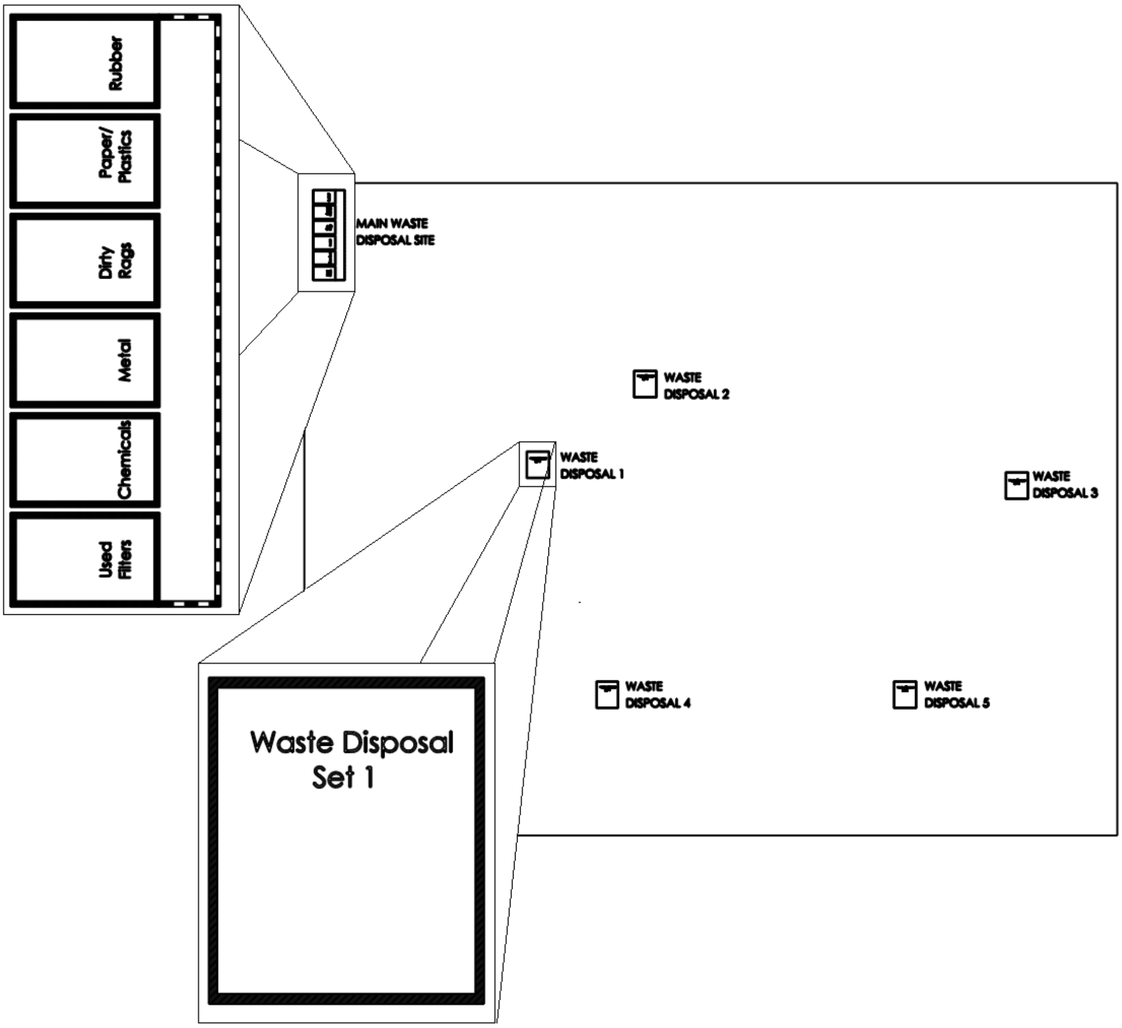

Figure 3.14 Scenario 1- solution 2, five aircrafts, three waste sets

3.6.2. Equipment labeling

Equipment labeling is a great way to motivate employees in their Lean and reliability initiatives [10]. Wrong equipment labeling can couse poor results in waste sorting (Fig 3.13.). It can be applied around the hangar to reinforce the principles of Lean performance. Self-sticking labels are available with a variety of pre-printed reliability messages.

Figure 3.15 Wrong labelling

To improve employes attention in waste sorting measure as additional waste sorting informational labeling have to be sticked on waste bin lid inner and outer surfaces and on main front facing surface (Fig. 3.14).

In this case all posible eye contact with waste bin during opening, closing and throwing in waste will be used efficiently to inform the employee of the type of waste waste bin stands for.

Figure 3.16 Scenario 1- solution 2, five aircrafts, three waste sets

Additional Lean manufacturing idea can be implemented to reduce waste time during waste bag replacement is adding extra waste bags on the bottom of the waste bin(Fig.3.15). This idea eliminates additional movement taken to search for, or walk to the stock for new bags every time bag has to be replaced. This improvement also helps to reduce information employee has to aquire about location about new bag storage location.

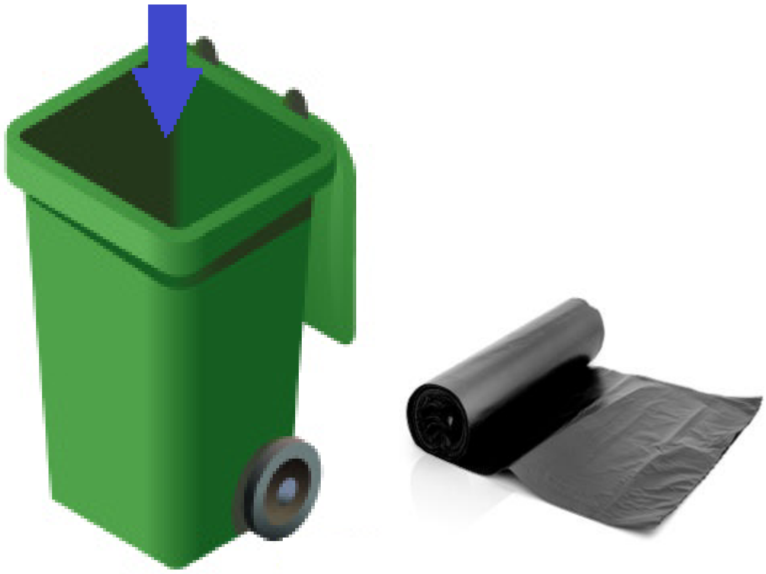

Figure 3.17 Scenario 1- solution 2, five aircrafts, three waste sets

3.7. Economical effectiveness

Further we calculate the cost of inventory.

Cost of waste bins, excluding taxes are recorded in Table 3.10, [30].

Table 3.10 Waste bin prices

Type of bin	MGB 60	MGB 80	MGB 120	MGB 140	MGB 240	MGB 340	MGB 370	MGB 770
Price (Eur)	23	23	25	29	32	50	55	90

$$E = P_{bin} \times Q_{bin} + P_{cradle} \times Q_{cradle} + H_{per\,year} \times C + P_{bin} \times L$$

P-price

Q-quantity

H-work hours

L-Lean finish

C-Labour cost

Comparison of waste bin installation costs is done by including Lean finish, bin costs, cradle cost. Every case scenario includes general waste bin set cost.

1. Credle cost is accepted as 200 Eur.
2. Lean finish is accepted as 5 Eur per waste bin.

Table 3.11 Installation cost

Case	Cost (Eur)				
	General bin	**Bin**	**Lean finish**	**Cradle**	**Total**
Scenario 1, solution 2, five aircrafts, 3 waste sets	271	471	90	600	1161
Scenario 1, solution 1, five aircrafts, 3 waste sets	271	468	90	600	1429
Scenario 2- solution 1, five aircraft, one waste set	0	241	30	0	271
Scenario 3- solution 1, one aircraft, one waste set	271	730	150	1000	2151
Scenario 3- solution 2, one aircraft, one waste set	271	750	150	1000	2171
Scenario 3- solution 3, five aircrafts, five waste sets	271	732	150	1000	2153
Scenario 4- solution 1, five aircrafts, four waste sets	271	600	120	800	1791
Scenario 4- solution 2, five aircrafts, four waste sets	271	599	120	800	1790

Labour time spent for waste disposal:

Accepting that hangar in employment is 6 months per year in maximum work load.

Average labour cost is accepted as (7,56 Eur/hour [31]. ”*Scenario 3- solution 1, one aircraft, one waste set*“, „*Scenario 3- solution 2, one aircraft, one waste set*“ – Not applicable for 5 aircraft results.

Table 3.12 Labour cost

Case	Time–hours per year	Labour cost (Eur)
Scenario 1, solution 2, five aircrafts, 3 waste sets	1514,04	11446,14
Scenario 1, solution 1, five aircrafts, 3 waste sets	1307,50	9884,7
Scenario 2- solution 1, five aircraft, one waste set	2427,49	18351,82
Scenario 3- solution 1, one aircraft, one waste set	*1152,5*	*8712,9*
Scenario 3- solution 2, one aircraft, one waste set	*1064,25*	*8045,73*
Scenario 3- solution 3, five aircrafts, five waste sets	1073,27	8113,9

Scenario 4- solution 1, five aircrafts, four waste sets	1131,95	8557,54
Scenario 4- solution 2, five aircrafts, four waste sets	1100,21	8317,58

The most inefficient new way to run would be ”*Scenario 2- solution 1, five aircraft, one waste set*“ – 18351.82 Eur additionaly for waste bins

Cheapest to run would be the „*Scenario 3- solution 3, five aircrafts, five waste sets*“ – 8113,9 Eur, for waste bins would be spent 1153 Eur.

The „*Scenario 3- solution 1, one aircraft, one waste set*“ would cost 10512 Eur, and expenses of inventory would be 730 Eur

Overall costs. Costs that would be needed for waste sorting system realization.

Table 3.13 Overall cost

Case	**Total cost (Eur)**
Scenario 1, solution 2, five aircrafts, 3 waste sets	12607,14
Scenario 1, solution 1, five aircrafts, 3 waste sets	11313,07
Scenario 2- solution 1, five aircraft, one waste set	18622,82
Scenario 3- solution 1, one aircraft, one waste set	*10863,90*
Scenario 3- solution 2, one aircraft, one waste set	*10216,73*
Scenario 3- solution 3, five aircrafts, five waste sets	10266,90
Scenario 4- solution 1, five aircrafts, four waste sets	10348,54
Scenario 4- solution 2, five aircrafts, four waste sets	10307,58

Table 3.14 Aircraft – recycle bin, waste route optimized results.

Solution type	Time	Cost	Change
Worst case scenario, current situation	3330,48	25178,42	
Scenario 2- solution 1, five aircraft, one waste set	2427,49	18622,82	-27,11 %
Scenario 1, solution 2, five aircrafts, 3 waste sets	1514,04	12607,14	-54,53 %
Scenario 1, solution 1, five aircrafts, 3 waste sets	1307,5	11313,07	-60,77 %
Scenario 4- solution 1, five aircrafts, four waste sets	1131,95	10348,54	-66,04 %
Scenario 3- solution 3, five aircrafts, five waste sets	1073,27	10266,9	-67,8 %

According to total cost of 10266.9 per year, the best waste sorting optimization scenario is „*scenario 3- solution 3, five aircrafts, five waste sets*“, Fig. 3.7, Table in Appendix No. 4.

CONCLUCIONS

1. The small aviation MRO have a tendency to work with smaller costumer companies who have smaller fleets of aircraft. This is because most bigger airlines prefer more expensive but more reliable partners.
2. The current case waste sorting analysis showed that most important factors that complicates waste sorting management are not implementing new ideas or trying to save cost in short term time. Furthermore, that choosing centralized waste disposal sets are the best for small quantities of waste, in our case we need to used centralized waste sorting sets to achieve minimum complexity and maximum productivity solution for waste disposal in aircraft maintenance hangar
3. Maintenance waste sorting is done differently in big MRO, but their approach is far too expensive to use in smaller organisations. This is because high equipment costs.
4. After the case scenario analysis conclusion can be done that waste sorting optimization by analysing different case scenarios for optimum results can be done to acquire reliable results, a deeper analysis needs to be done for proper argumentation of the developed methodology.
5. After the on job practical training in aircraft MRO it can be stated that:
   - most efficient way of positioning waste bins is by collecting them to set of 6 waste bins and positioning them on hangar perimeter by placing them on special cradle;
   - the cost of the cradle 200 Euros;
   - that waste sorting takes a lot of time and it should be managed more efficiently.
6. After the modelling case scenarios and waste management study it can be concluded that:
   - after overview of current waste management system in aircraft maintenance and repair organization we managed to research current waste disposal effectivity. The most efficient way of waste sorting during 5 aircraft heavy maintenance process is to use 5 waste bin sets that are parked in calculated positions with total of 30 waste bins.
   - decision of waste bin volumes that are used in the process has bin made. And for reliable operation 25 litres of volume has been added to prevent overfilling.
   - after overview the concept of Lean manufacturing we picked the most useful management ideas to get best results during our waste sorting optimization process. applied Lean ideas helped to reduce loss of time and increase waste sorting efficiency in aircraft maintenance processes.

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APPENDIX

Appendix No. 1

Scenario 1: Solution 1 – five Aircrafts, three waste bin sets

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	1	27,53			34,41	0	0	34,41	91	3131,54
Zone 2		5,62			7,03	0	0	7,03	176	1236,40
Zone 3		12,91			16,14	0	0	16,14	276	4453,95
Zone 4		13,85			17,31	0	0	17,31	75	1298,44
Zone 5		27,95			34,94	0	0	34,94	74	2585,38
Zone 6		27,95			34,94	0	0	34,94	34	1187,88
Zone 7		25,91			32,39	0	0	32,39	44,4	1438,01
Zone 8		23,15			28,94	0	0	28,94	52,2	1510,54
Zone 9		13,77			17,21	0	0	17,21	65	1118,81
Zone 10		19,71			24,64	0	0	24,64	38	936,23
Zone 11		16,08			20,10	0	0	20,10	17	341,70

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1				12,4	0,00	0	15,50	15,50	91	1410,50
Zone 2			16,9		0,00	21,13	0	21,13	176	3718,00
Zone 3		24,73			30,91	0	0	30,91	276	8531,85
Zone 4		24,39			30,49	0	0	30,49	75	2286,56
Zone 5				22,74	0,00	0	28,43	28,43	74	2103,45
Zone 6	2			19,21	0,00	0	24,01	24,01	34	816,43
Zone 7				18,86	0,00	0	23,58	23,58	44,4	1046,73
Zone 8				17,29	0,00	0	21,61	21,61	52,2	1128,17
Zone 9		15,93			19,91	0	0	19,91	65	1294,31
Zone 10				16,72	0,00	0	20,90	20,90	38	794,20
Zone 11		19,71			24,64	0	0	24,64	17	418,84
Zone 1			24,91		0,00	31,14	0	31,14	91	2833 ,51
Zone 2			12,52		0,00	15,65	0	15,65	176	2754,40
Zone 3			12,54		0,00	15,68	0	15,68	276	4326,30
Zone 4			13,73		0,00	17,16	0	17,16	75	1287,19
Zone 5		15,93	19,7		19,91	24,63	0	44,54	74	3295,78
Zone 6	3		28,33		0,00	35,41	0	35,41	34	1204,03
Zone 7			25,1		0,00	31,38	0	31,38	44,4	1393,05
Zone 8			22,94		0,00	28,68	0	28,68	52,2	1496,84
Zone 9			3,36		0,00	4,20	0	4,20	65	273,00
Zone 10			17,15		0,00	21,44	0	21,44	38	814,63
Zone 11			15,28		0,00	19,10	0,00	19,10	17	324,70

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	4	21,66			27,08	0	0,00	27,08	91	2463,83
Zone 2				26,25	0,00	0	32,81	32,81	176	5775,00
Zone 3				22,56	0,00	0	28,20	28,20	276	7783,20
Zone 4				19,37	0,00	0	24,21	24,21	75	1815,94
Zone 5				29,86	0,00	0	37,33	37,33	74	2762,05
Zone 6		18,66			23,33	0	0,00	23,33	34	793,05
Zone 7				21,58	0,00	0	26,98	26,98	44,4	1197,69
Zone 8				24,3	0,00	0	30,38	30,38	52,2	1585,58
Zone 9				17,61	0,00	0	22,01	22,01	65	1430,81
Zone 10		26,19			32,74	0	0,00	32,74	38	1244,03
Zone 11				26,4	0,00	0	33,00	33,00	17	561,00
Zone 1	5		20,9		0,00	26,13	0,00	26,13	91	2377,38
Zone 2				14,4	0,00	0	18,00	18,00	176	3168,00
Zone 3				19,59	0,00	0	24,49	24,49	276	6758,55
Zone 4				27,02	0,00	0	33,78	33,78	75	2533,13
Zone 5				16,89	0,00	0	21,11	21,11	74	1562,33
Zone 6			18,45		0,00	23,06	0,00	23,06	34	784,13
Zone 7				19,74	0,00	0	24,68	24,68	44,4	1095,57
Zone 8				21,96	0,00	0	27,45	27,45	52,2	1432,89
Zone 9				22,89	0,00	0	28,61	28,61	65	1859,81
Zone 10			26,9		0,00	33,63	0,00	33,63	38	1277,75
Zone 11				23,54	0,00	0	29,43	29,43	17	500,23

Appendix No. 2

Scenario 1. Solution 1 – five aircrafts, three waste bin sets. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Minimal bin capacity	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	18	11,75	40,5	7,26	11,5	10	2,25	6,83	4,76	4,76	2,26	119,87	140
	Dirty rags	18,5	16	48,5	17	15	3,5	8,5	11,25	26,5	13,5	3	181,25	240
	Used filters	0	0	0,26	0,76	0,76	0	0	0,5	0,26	0	0	2,54	60
	Metal	0,76	0,13	0,76	0,76	0,76	0,26	0,05	0,08	1	0,26	0,26	5,08	60
	Rubber	10	6	13,5	9,5	9,5	5	2	2,5	5,5	8,5	4,5	76,5	120
	Chemicals	1	0,5	2	4	4	1	0,75	0,5	0,5	0,5	0	14,75	60
2	Paper/plastic	18	23,5	40,5	7,26	11,5	10	2,25	2,13	13,66	4,76	2,26	135,82	240
	Dirty rags	18,5	32	24,25	8,5	7,5	3,5	8,5	11,25	13,25	13,5	1,5	142,25	240
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0,76	0,26	0,38	0,38	0,38	0,26	0,05	0,08	0,5	0,26	0,13	3,44	60
	Rubber	10	12	6,75	4,75	4,75	5	2	2,5	2,75	8,5	2,25	61,25	120
	Chemicals	1	1	1	2	2	1	0,75	0,5	0,25	0,5	0	10	60
3	Paper/plastic	9	23,5	40,5	7,26	11,5	5	6,75	6,39	13,66	2,38	2,26	128,2	240
	Dirty rags	9,25	23,5	40,5	11,5	15	1,75	25,5	33,75	26,5	6,75	3	197	240
	Used filters	0	0	0,26	0,76	0,76	0	0	1,5	0,26	0	0	3,54	60
	Metal	0,38	0,26	0,76	0,76	0,76	0,13	0,15	0,24	1	0,13	0,26	4,83	60
	Rubber	5	12	13,5	9,5	9,5	0,5	6	7,5	5,5	4,25	4,5	77,75	120
	Chemicals	0,5	1	2	4	4	0,5	2,25	1,5	0,5	0,25	0	16,5	60

Appendix No. 3

Scenario 1: Solution 2 – five aircrafts, three waste bin sets

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Timeof disposal (s)
Zone 1		4,17			5,21	0,00	0,00	5,21	91,00	474,34
Zone 2		26,71			33,39	0,00	0,00	33,39	176,00	5876,20
Zone 3		15,49			19,36	0,00	0,00	19,36	276,00	5344,05
Zone 4		9,12			11,40	0,00	0,00	11,40	75,00	855,00
Zone 5		16,19			20,24	0,00	0,00	20,24	74,00	1497,58
Zone 6	1	9,91			12,39	0,00	0,00	12,39	34,00	421,18
Zone 7		4,92			6,15	0,00	0,00	6,15	44,40	273,06
Zone 8		4,92			6,15	0,00	0,00	6,15	52,20	321,03
Zone 9		24,11			30,14	0,00	0,00	30,14	65,00	1958,94
Zone 10		11,86			14,83	0,00	0,00	14,83	38,00	563,35
Zone 11		36,06			45,08	0,00	0,00	45,08	17,00	766,28
Zone 1				11,81	0,00	0,00	14,76	14,76	91,00	1343,39
Zone 2			5,52		0,00	6,90	0,00	6,90	176,00	1214,40
Zone 3			12,14		0,00	15,18	0,00	15,18	276,00	4188,30
Zone 4				17,74	0,00	0,00	22,18	22,18	75,00	1663,13
Zone 5				10,01	0,00	0,00	12,51	12,51	74,00	925,93
Zone 6	2			7,11	0,00	0,00	8,89	8,89	34,00	302,18
Zone 7				16,87	0,00	0,00	21,09	21,09	44,40	936,29
Zone 8				13,22	0,00	0,00	16,53	16,53	52,20	862,61
Zone 9			13,69		0,00	17,11	0,00	17,11	65,00	1112,31
Zone 10				6,41	0,00	0,00	8,01	8,01	38,00	304,48
Zone 11			17,02		0,00	21,28	0,00	21,28	17,00	361,68

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1				17,63	0,00	0,00	22,04	22,04	91,00	2005,41
Zone 2			24,42		0,00	30,53	0,00	30,53	176,00	5372,40
Zone 3			18,49		0,00	23,11	0,00	23,11	276,00	6379,05
Zone 4			13,42		0,00	16,78	0,00	16,78	75,00	1258,13
Zone 5			24,87		0,00	31,09	0,00	31,09	74,00	2300,48
Zone 6	3			21,85	0,00	0,00	27,31	27,31	34,00	928,63
Zone 7			28,11		0,00	35,14	0,00	35,14	44,40	1560,11
Zone 8			24,67		0,00	30,84	0,00	30,84	52,20	1609,72
Zone 9			16,17		0,00	20,21	0,00	20,21	65,00	1313,81
Zone 10			16,12		0,00	20,15	0,00	20,15	38,00	765,70
Zone 11			28,48		0,00	35,60	0,00	35,60	17,00	605,20
Zone 1		19,19			23,99	0,00	0,00	23,99	91,00	2182,86
Zone 2		26,92			33,65	0,00	0,00	33,65	176,00	5922,40
Zone 3		20,66			25,83	0,00	0,00	25,83	276,00	7127,70
Zone 4				22,18	0,00	0,00	27,73	27,73	75,00	2079,38
Zone 5		13,07			16,34	0,00	0,00	16,34	74,00	1208,98
Zone 6	4	17,18			21,48	0,00	0,00	21,48	34,00	730,15
Zone 7				20,78	0,00	0,00	25,98	25,98	44,40	1153,29
Zone 8		19,62			24,53	0,00	0,00	24,53	52,20	1280,21
Zone 9				28,49	0,00	0,00	35,61	35,61	65,00	2314,81
Zone 10		10,9			13,63	0,00	0,00	13,63	38,00	517,75
Zone 11				38,97	0,00	0,00	48,71	48,71	17,00	828,11

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time of disposal (s)	Frequency of disposal	Total Time(s) of disposal
Zone 1	5		18,1		0,00	22,63	0,00	22,63	91,00	2058,88
Zone 2				17,06	0,00	0,00	21,33	21,33	176,00	3753,20
Zone 3				12,36	0,00	0,00	15,45	15,45	276,00	4264,20
Zone 4				17,72	0,00	0,00	22,15	22,15	75,00	1661,25
Zone 5				5,54	0,00	0,00	6,93	6,93	74,00	512,45
Zone 6			15,45		0,00	19,31	0,00	19,31	34,00	656,63
Zone 7				6,35	0,00	0,00	7,94	7,94	44,40	352,43
Zone 8				9,17	0,00	0,00	11,46	11,46	52,20	598,34
Zone 9				22,16	0,00	0,00	27,70	27,70	65,00	1800,50
Zone 10				16,46	0,00	0,00	20,58	20,58	38,00	781,85
Zone 11				28,98	0,00	0,00	36,23	36,23	17,00	615,83

Appendix No. 4

Scenario 1: Solution 2 – five aircrafts, three waste bin sets. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	18	23,5	40,5	3,63	11,5	10	2,25	6,83	4,76	4,76	1,13	126,86	240
	Dirty rags	18,5	32	48,5	8,5	15	3,5	8,5	22,5	13,25	13,5	1,5	185,25	240
	Used filters	0	0	0,26	0,38	0,76	0	0	1	0,13	0	0	2,53	60
	Metal	0,76	0,26	0,76	0,38	0,76	0,26	0,05	0,16	0,5	0,26	0,13	4,28	60
	Rubber	10	12	13,5	4,75	9,5	5	2	5	2,75	8,5	2,25	75,25	120
	Chemicals	1	1	2	2	4	1	0,75	1	0,25	0,5	0	13,5	60
2	Paper/plastic	9	23,5	40,5	3,63	11,5	10	2,25	2,13	6,83	4,76	1,13	115,23	140
	Dirty rags	9,25	32	48,5	8,5	7,5	1,75	8,5	11,25	26,5	6,75	3	163,5	240
	Used filters	0	0	0,26	0,38	0,38	0	0	0,5	0,26	0	0	1,78	60
	Metal	0,38	0,26	0,76	0,38	0,38	0,13	0,05	0,08	1	0,13	0,26	3,81	60
	Rubber	5	12	13,5	4,75	4,75	2,5	2	2,5	5,5	4,25	4,5	61,25	120
	Chemicals	0,5	1	2	2	2	0,5	0,75	0,5	0,5	0,25	0	10	60

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Chosen bin capacity
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
3	**Paper/plastic**	18	11,75	20,25	10,89	11,5	10	6,75	4,26	13,66	4,76	2,26	114,08	140
	Dirty rags	18,5	11,75	20,25	17,25	15	3,5	25,5	22,5	26,5	13,5	3	177,25	240
	Used filters	0	0	0,13	1,14	0,76	0	0	1	0,26	0	0	3,29	60
	Metal	0,76	0,13	0,38	1,14	0,76	0,26	0,15	0,16	1	0,26	0,26	5,26	60
	Rubber	10	6	6,75	14,25	9,5	1	6	5	5,5	8,5	4,5	77	120
	Chemicals	1	0,5	1	6	4	1	2,25	1	0,5	0,5	0	17,75	60

Appendix No. 5

Scenario 1: Solution 3 – five aircrafts, one waste set

Waste source	Aircraft No.	Distance to Set 1 (m)	Time on Distance to set 1 (s)	Time of disposal (s)	Frequency of disposal	Total Time(s) of disposal
Zone 1	1	39,98	49,98	49,98	91,00	4547,73
Zone 2		27,42	34,28	34,28	176,00	6032,40
Zone 3		29,38	36,73	36,73	276,00	10136,10
Zone 4		29,45	36,81	36,81	75,00	2760,94
Zone 5		37,03	46,29	46,29	74,00	3425,28
Zone 6		44,67	55,84	55,84	34,00	1898,48
Zone 7		33,19	41,49	41,49	44,40	1842,05
Zone 8		35,19	43,99	43,99	52,20	2296,15
Zone 9		19,67	24,59	24,59	65,00	1598,19
Zone 10		39,58	49,48	49,48	38,00	1880,05
Zone 11		28,89	36,11	36,11	17,00	613,91
Zone 1	2	62,99	78,74	78,74	91,00	7165,11
Zone 2		56,3	70,38	70,38	176,00	12386,00
Zone 3		56,46	70,58	70,58	276,00	19478,70
Zone 4		53,99	67,49	67,49	75,00	5061,56
Zone 5		64,04	80,05	80,05	74,00	5923,70
Zone 6		68,18	85,23	85,23	34,00	2897,65
Zone 7		56,36	70,45	70,45	44,40	3127,98
Zone 8		59,18	73,98	73,98	52,20	3861,50
Zone 9		48,54	60,68	60,68	65,00	3943,88
Zone 10		65,48	81,85	81,85	38,00	3110,30
Zone 11		49,35	61,69	27,42	17,00	466,08

Waste source	Aircraft No.	Distance to Set 1 (m)	Time on Distance to set 1 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1		81,66	102,08	102,08	91,00	9288,83
Zone 2		81,81	102,26	102,26	176,00	17998,20
Zone 3		79,5	99,38	99,38	276,00	27427,50
Zone 4		75,24	94,05	94,05	75,00	7053,75
Zone 5		86,5	108,13	108,13	74,00	8001,25
Zone 6	3	87,2	109,00	109,00	34,00	3706,00
Zone 7		89,91	112,39	112,39	44,40	4990,01
Zone 8		86,39	107,99	107,99	52,20	5636,95
Zone 9		72,8	91,00	91,00	65,00	5915,00
Zone 10		77,76	97,20	97,20	38,00	3693,60
Zone 11		76,74	95,93	95,93	17,00	1630,73
Zone 1		46,77	58,46	58,46	91,00	5320,09
Zone 2		63,71	79,64	79,64	176,00	14016,20
Zone 3		56,12	70,15	70,15	276,00	19361,40
Zone 4		55,74	69,68	69,68	75,00	5225,63
Zone 5		49,11	61,39	61,39	74,00	4542,68
Zone 6	4	43,03	53,79	53,79	34,00	1828,78
Zone 7		53	66,25	66,25	44,40	2941,50
Zone 8		50,44	63,05	63,05	52,20	3291,21
Zone 9		67,69	84,61	84,61	65,00	5499,81
Zone 10		44,32	55,40	55,40	38,00	2105,20
Zone 11		75,7	94,63	94,63	17,00	1608,63

Waste source	Aircraft No.	Distance to Set 1 (m)	Time on Distance to set 1 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	5	79,02	98,78	98,78	91,00	8988,53
Zone 2		87,18	108,98	108,98	176,00	19179,60
Zone 3		83,67	104,59	104,59	276,00	28866,15
Zone 4		86,53	108,16	108,16	75,00	8112,19
Zone 5		76,35	95,44	95,44	74,00	7062,38
Zone 6		76,57	95,71	95,71	34,00	3254,23
Zone 7		72,27	90,34	90,34	44,40	4010,99
Zone 8		75,47	94,34	94,34	52,20	4924,42
Zone 9		93,76	117,20	117,20	65,00	7618,00
Zone 10		82,22	102,78	102,78	38,00	3905,45
Zone 11		98,03	122,54	122,54	17,00	2083,14

Appendix No. 6

Scenario 1. Solution 3: five Aircrafts, one Waste Set. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity (l)	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	45	58,75	101,25	18,15	28,75	10	2,25	6,83	4,76	11,9	5,65	293,29	340
	Dirty rags	46,25	80	121,25	42,5	37,5	8,75	42,5	56,25	66,25	33,75	7,5	542,5	770
	Used filters	0	0	0,65	1,9	1,9	0	0	2,5	0,65	0	0	7,6	60
	Metal	1,9	0,65	1,9	1,9	1,9	0,65	0,25	0,4	2,5	0,65	0,65	13,35	60
	Rubber	25	30	33,75	23,75	23,75	12,5	10	12,5	13,75	21,25	11,25	217,5	240
	Chemicals	2,5	2,5	5	10	10	2,5	3,75	2,5	1,25	1,25	0	41,25	80

Appendix No. 7

Scenario 3. Solution 1 – five aircrafts, four waste bin sets

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	1	27,5				34,41	0,00	0,00	0,00	34,41	91,00	3131,54
Zone 2		5,03				6,29	0,00	0,00	0,00	6,29	176,00	1106,60
Zone 3		12,9				16,14	0,00	0,00	0,00	16,14	276,00	4453,95
Zone 4		20,3				25,36	0,00	0,00	0,00	25,36	75,00	1902,19
Zone 5		13,9				17,31	0,00	0,00	0,00	17,31	74,00	1281,13
Zone 6		28				34,94	0,00	0,00	0,00	34,94	34,00	1187,88
Zone 7		25,9				32,39	0,00	0,00	0,00	32,39	44,40	1438,01
Zone 8		23,2				28,94	0,00	0,00	0,00	28,94	52,20	1510,54
Zone 9		13,7				17,11	0,00	0,00	0,00	17,11	65,00	1112,31
Zone 10		19,7				24,64	0,00	0,00	0,00	24,64	38,00	936,23
Zone 11		16,1				20,10	0,00	0,00	0,00	20,10	17,00	341,70
Zone 1	2			13		0,00	0,00	16,80	0,00	16,80	91,00	1528,80
Zone 2			18,51			0,00	23,14	0,00	0,00	23,14	176,00	4072,20
Zone 3		24,7				30,91	0,00	0,00	0,00	30,91	276,00	8531,85
Zone 4				23		0,00	0,00	28,75	0,00	28,75	75,00	2156,25
Zone 5					23	0,00	0,00	0,00	28,69	22,95	74,00	1698,30
Zone 6				14		0,00	0,00	18,00	0,00	18,00	34,00	612,00
Zone 7				17		0,00	0,00	20,75	0,00	20,75	44,40	921,30
Zone 8				18		0,00	0,00	22,14	0,00	22,14	52,20	1155,58
Zone 9		15,9				19,91	0,00	0,00	0,00	19,91	65,00	1294,31
Zone 10					19	0,00	0,00	0,00	23,28	18,62	38,00	707,56
Zone 11		19,2				24,01	0,00	0,00	0,00	24,01	17,00	408,21

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1					21	0,00	0,00	0,00	26,41	21,13	91,00	1922,83
Zone 2			10,4			0,00	13,00	0,00	0,00	13,00	176,00	2288,00
Zone 3			10,14			0,00	12,68	0,00	0,00	12,68	276,00	3498,30
Zone 4			12,24			0,00	15,30	0,00	0,00	15,30	75,00	1147,50
Zone 5			17,22			0,00	21,53	0,00	0,00	21,53	74,00	1592,85
Zone 6	3				23	0,00	0,00	0,00	28,24	22,59	34,00	768,06
Zone 7			22,73			0,00	28,41	0,00	0,00	28,41	44,40	1261,52
Zone 8			22,72			0,00	28,40	0,00	0,00	28,40	52,20	1482,48
Zone 9			1,87			0,00	2,34	0,00	0,00	2,34	65,00	151,94
Zone 10			15,51			0,00	19,39	0,00	0,00	19,39	38,00	736,73
Zone 11			15,36			0,00	19,20	0,00	0,00	19,20	17,00	326,40
Zone 1		16				20,01	0,00	0,00	0,00	20,01	91,00	1821,14
Zone 2				14		0,00	0,00	17,83	0,00	17,83	176,00	3137,20
Zone 3				12		0,00	0,00	14,64	0,00	14,64	276,00	4039,95
Zone 4				12		0,00	0,00	15,30	0,00	15,30	75,00	1147,50
Zone 5				19		0,00	0,00	24,18	0,00	24,18	74,00	1788,95
Zone 6	4	18,7				23,33	0,00	0,00	0,00	23,33	34,00	793,05
Zone 7				17		0,00	0,00	21,26	0,00	21,26	44,40	944,06
Zone 8				18		0,00	0,00	22,28	0,00	22,28	52,20	1162,76
Zone 9				6,2		0,00	0,00	7,79	0,00	7,79	65,00	506,19
Zone 10		19,7				24,64	0,00	0,00	0,00	24,64	38,00	936,23
Zone 11				18		0,00	0,00	22,05	0,00	22,05	17,00	374,85

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1			19,29			0,00	24,11	0,00	0,00	24,11	91,00	2194,24
Zone 2					4,7	0,00	0,00	0,00	5,90	4,72	176,00	830,72
Zone 3					9	0,00	0,00	0,00	11,20	8,96	276,00	2472,96
Zone 4					16	0,00	0,00	0,00	20,56	16,45	75,00	1233,75
Zone 5					11	0,00	0,00	0,00	13,81	11,05	74,00	817,70
Zone 6	5		17,28			0,00	21,60	0,00	0,00	21,60	34,00	734,40
Zone 7					16	0,00	0,00	0,00	20,10	16,08	44,40	713,95
Zone 8					16	0,00	0,00	0,00	20,10	16,08	52,20	839,38
Zone 9					11	0,00	0,00	0,00	14,11	11,29	65,00	733,85
Zone 10					19	0,00	0,00	0,00	23,88	19,10	38,00	725,80
Zone 11					17	0,00	0,00	0,00	20,83	16,66	17,00	283,22

Appendix No. 8

Scenario 3. Solution 1 – five aircrafts, four waste bin sets. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity (l)	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	18	11,75	40,5	3,63	5,75	10	2,25	6,83	4,76	4,76	2,26	110,49	140
	Dirty rags	18,5	16	48,5	8,5	7,5	3,5	8,5	11,25	26,5	13,5	3	165,25	240
	Used filters	0	0	0,26	0,38	0,38	0	0	0,5	0,26	0	0	1,78	60
	Metal	0,76	0,13	0,76	0,38	0,38	0,26	0,05	0,08	1	0,26	0,26	4,32	60
	Rubber	10	6	13,5	4,75	4,75	5	2	2,5	5,5	8,5	4,5	67	120
	Chemicals	1	0,5	2	2	2	1	0,75	0,5	0,5	0,5	0	10,75	60
2	Paper/plastic	9	23,5	40,5	3,63	5,75	10	2,25	2,13	13,66	4,76	2,26	117,44	140
	Dirty rags	9,25	32	24,25	8,5	7,5	1,75	8,5	11,25	13,25	6,75	1,5	124,5	240
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0,38	0,26	0,38	0,38	0,38	0,13	0,05	0,08	0,5	0,13	0,13	2,8	60
	Rubber	5	12	6,75	4,75	4,75	2,5	2	2,5	2,75	4,25	2,25	49,5	80
	Chemicals	0,5	1	1	2	2	0,5	0,75	0,5	0,25	0,25	0	8,75	60

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity (l)	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
3	Paper/plastic	9	23,5	20,25	7,26	5,75	5	4,5	2,13	6,83	0	1,13	85,35	120
	Dirty rags	9,25	23,5	20,25	11,5	7,5	1,75	17	11,25	13,25	0	1,5	116,75	140
	Used filters	0	0	0,13	0,76	0,38	0	0	0,5	0,13	0	0	1,9	60
	Metal	0,38	0,26	0,38	0,76	0,38	0,13	0,1	0,08	0,5	0	0,13	3,1	60
	Rubber	5	12	6,75	9,5	4,75	0,5	4	2,5	2,75	0	2,25	50	80
	Chemicals	0,5	1	1	4	2	0,5	1,5	0,5	0,25	0	0	11,25	60
4	Paper/plastic	9	0	20,25	3,63	11,5	5	2,25	4,26	6,83	4,76	1,13	68,61	120
	Dirty rags	9,25	0	24,25	8,5	15	1,75	8,5	22,5	13,25	13,5	1,5	118	140
	Used filters	0	0	0,13	8,5	0,76	0	0	1	0,13	0	0	10,52	60
	Metal	0,38	0	0,38	0,38	0,76	0,13	0,05	1	0,5	0,26	0,13	3,97	60
	Rubber	5	0	6,75	4,75	9,5	2,5	2	5	2,75	8,5	2,25	49	80
	Chemicals	0,5	0	1	2	4	0,5	0,75	1	0,25	0,5	0	10,5	60

Appendix No. 9

Scenario 3. Solution 2 – five aircrafts, four waste bin sets

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1		5,02				6,28	0,00	0,00	0,00	6,28	91,00	571,03
Zone 2		27,12				33,90	0,00	0,00	0,00	33,90	176,00	5966,40
Zone 3		15,94				19,93	0,00	0,00	0,00	19,93	276,00	5499,30
Zone 4		9,32				11,65	0,00	0,00	0,00	11,65	75,00	873,75
Zone 5		16,97				21,21	0,00	0,00	0,00	21,21	74,00	1569,73
Zone 6	1	10,75				13,44	0,00	0,00	0,00	13,44	34,00	456,88
Zone 7		3,51				4,39	0,00	0,00	0,00	4,39	44,40	194,81
Zone 8		5,61				7,01	0,00	0,00	0,00	7,01	52,20	366,05
Zone 9		24,24				30,30	0,00	0,00	0,00	30,30	65,00	1969,50
Zone 10		12,74				40	0,00	0,00	0,00	28,5	38,00	2005
Zone 11		36,25				45,31	0,00	0,00	0,00	45,31	17,00	770,31
Zone 1			12,46			0,00	15,58	0,00	0,00	15,58	91,00	1417,33
Zone 2				17,61		0,00	0,00	22,01	0,00	22,01	176,00	3874,20
Zone 3			11,38			0,00	14,23	0,00	0,00	14,23	276,00	3926,10
Zone 4			4,38			0,00	5,48	0,00	0,00	5,48	75,00	410,63
Zone 5				7,69		0,00	0,00	9,61	0,00	9,61	74,00	711,33
Zone 6	2		16,66			0,00	20,83	0,00	0,00	20,83	34,00	708,05
Zone 7			5,98			0,00	7,48	0,00	0,00	7,48	44,40	331,89
Zone 8			8,19			0,00	10,24	0,00	0,00	10,24	52,20	534,40
Zone 9			15,51			0,00	19,39	0,00	0,00	19,39	65,00	1260,19
Zone 10				10,94		0,00	0,00	13,68	0,00	13,68	38,00	519,65
Zone 11			28,78			0,00	35,98	0,00	0,00	35,98	17,00	611,58

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	3			10,1		0,00	0,00	12,63	0,00	12,63	91,00	1148,88
Zone 2					23,57	0,00	0,00	0,00	29,46	23,57	176,00	4148,32
Zone 3					16,83	0,00	0,00	0,00	21,04	16,83	276,00	4645,08
Zone 4				11,64		0,00	0,00	14,55	0,00	14,55	75,00	1091,25
Zone 5					10,04	0,00	0,00	0,00	12,55	10,04	74,00	742,96
Zone 6					9,72	0,00	0,00	0,00	12,15	9,72	34,00	330,48
Zone 7					4,26	0,00	0,00	0,00	5,33	4,26	44,40	189,14
Zone 8					7,35	0,00	0,00	0,00	9,19	7,35	52,20	383,67
Zone 9					26,97	0,00	0,00	0,00	33,71	26,97	65,00	1753,05
Zone 10				10,96		0,00	0,00	13,70	0,00	13,70	38,00	520,60
Zone 11				10,1		0,00	0,00	12,63	0,00	12,63	91,00	1148,88
Zone 1	4		12,46			0,00	15,58	0,00	0,00	15,58	91,00	1417,33
Zone 2				17,61		0,00	0,00	22,01	0,00	22,01	176,00	3874,20
Zone 3			11,38			0,00	14,23	0,00	0,00	14,23	276,00	3926,10
Zone 4			4,38			0,00	5,48	0,00	0,00	5,48	75,00	410,63
Zone 5				7,69		0,00	0,00	9,61	0,00	9,61	74,00	711,33
Zone 6			16,66			0,00	20,83	0,00	0,00	20,83	34,00	708,05
Zone 7			5,98			0,00	7,48	0,00	0,00	7,48	44,40	331,89
Zone 8			8,19			0,00	10,24	0,00	0,00	10,24	52,20	534,40
Zone 9			15,51			0,00	19,39	0,00	0,00	19,39	65,00	1260,19
Zone 10				10,94		0,00	0,00	13,68	0,00	13,68	38,00	519,65
Zone 11			12,46			0,00	15,58	0,00	0,00	15,58	91,00	1417,33

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1	5			9,55		0,00	0,00	11,94	0,00	11,94	91,00	1086,31
Zone 2				25,39		0,00	0,00	31,74	0,00	31,74	176,00	5585,80
Zone 3				15,51		0,00	0,00	19,39	0,00	19,39	276,00	5350,95
Zone 4					15,41	0,00	0,00	0,00	19,26	15,41	75,00	1155,75
Zone 5				9,8		0,00	0,00	12,25	0,00	12,25	74,00	906,50
Zone 6				8,3		0,00	0,00	10,38	0,00	10,38	34,00	352,75
Zone 7				5,2		0,00	0,00	6,50	0,00	6,50	44,40	288,60
Zone 8				5,49		0,00	0,00	6,86	0,00	6,86	52,20	358,22
Zone 9				27,34		0,00	0,00	34,18	0,00	34,18	65,00	2221,38
Zone 10				10,96		0,00	0,00	13,70	0,00	13,70	38,00	520,60
Zone 11				36,95		0,00	0,00	46,19	0,00	46,19	17,00	785,19

Appendix No. 10

Scenario 3. Solution 2 – five aircrafts, four waste bin sets. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity (l)	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	9	11,75	20,25	3,63	11,5	10	2,25	6,83	4,76	4,76	1,13	85,86	120
	Dirty rags	9,25	16	24,25	8,5	15	1,75	8,5	11,25	13,25	13,5	1,5	122,75	240
	Used filters	0	0	0,13	0,38	0,76	0	0	0,5	0,13	0	0	1,9	60
	Metal	0,38	0,13	0,38	0,38	0,76	0,13	0,05	0,08	0,5	0,26	0,13	3,18	60
	Rubber	5	6	6,75	4,75	9,5	2,5	2	2,5	2,75	8,5	2,25	52,5	80
	Chemicals	0,5	0,5	1	2	4	0,5	0,75	0,5	0,25	0,5	0	10,5	60
2	Paper/plastic	18	11,75	20,25	3,63	11,5	5	2,25	2,13	6,83	4,76	1,13	87,23	120
	Dirty rags	18,5	16	48,5	17	0	3,5	17	22,5	26,5	0	3	172,5	240
	Used filters	0	0	0,26	0,76	0	0	0	1	0,26	0	0	2,28	60
	Metal	0,76	0,13	0,76	0,76	0	0,26	0,1	0,16	1	0	0,26	4,19	60
	Rubber	10	6	13,5	9,5	0	5	4	5	5,5	0	4,5	63	120
	Chemicals	1	0,5	2	4	0	1	1,5	1	0,5	0	0	11,5	60

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity (l)	Choosen bin capacity (l)
		1	2	3	4	5	6	7	8	9	10	11		
3	Paper/plastic	18	23,5	20,25	3,63	11,5	5	2,25	2,13	6,83	7,14	1,13	101,36	140
	Dirty rags	18,5	23,5	20,25	5,75	15	1,75	8,5	11,25	13,25	20,25	1,5	139,5	240
	Used filters	0	0	0,13	0,38	0,76	0	0	0,5	0,13	0	0	1,9	60
	Metal	0,76	0,26	0,38	0,38	0,76	0,13	0,05	0,08	0,5	0,39	0,13	3,82	60
	Rubber	10	12	6,75	4,75	9,5	0,5	2	2,5	2,75	12,75	2,25	65,75	120
	Chemicals	1	1	1	2	4	0,5	0,75	0,5	0,25	0,75	0	11,75	60
4	Paper/plastic	0	11,75	20,25	3,63	5,75	5	2,25	2,13	6,83	0	1,13	58,72	80
	Dirty rags	0	16	24,25	8,5	7,5	1,75	8,5	11,25	13,25	0	1,5	92,5	140
	Used filters	0	0	0,13	8,5	0,38	0	0	0,5	0,13	0	0	9,64	60
	Metal	0	0,13	0,38	0,38	0,38	0,13	0,05	0,5	0,5	0	0,13	2,58	60
	Rubber	0	6	6,75	4,75	4,75	2,5	2	2,5	2,75	0	2,25	34,25	60
	Chemicals	0	0,5	1	2	2	0,5	0,75	0,5	0,25	0	0	7,5	60

Appendix No. 11

Scenario 2. Solution 2 – five aircrafts, five waste bin sets

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Distance to Set 5 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time on Distance to set 5 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1		12,31					15,39	0,00	0,00	0,00	0,00	15,39	91,00	1400,26
Zone 2		18					22,50	0,00	0,00	0,00	0,00	22,50	176,00	3960,00
Zone 3		11					13,75	0,00	0,00	0,00	0,00	13,75	276,00	3795,00
Zone 4		14,34					17,93	0,00	0,00	0,00	0,00	17,93	75,00	1344,38
Zone 5		3,72					4,65	0,00	0,00	0,00	0,00	4,65	74,00	344,10
Zone 6	1	12,31					15,39	0,00	0,00	0,00	0,00	15,39	34,00	523,18
Zone 7		16,7					20,88	0,00	0,00	0,00	0,00	20,88	44,40	926,85
Zone 8		13,39					16,74	0,00	0,00	0,00	0,00	16,74	52,20	873,70
Zone 9		21					26,25	0,00	0,00	0,00	0,00	26,25	65,00	1706,25
Zone 10		4,92					12,86	0,00	0,00	0,00	0,00	12,86	38,00	488,78
Zone 11			29,6				0,00	37,00	0,00	0,00	0,00	37,00	17,00	629,00

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Distance to Set 5 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time on Distance to set 5 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1					13,5		0,00	0,00	0,00	16,88	0,00	16,88	91,00	1535,63
Zone 2			10,5				0,00	13,13	0,00	0,00	0,00	13,13	176,00	2310,00
Zone 3			11,3				0,00	14,13	0,00	0,00	0,00	14,13	276,00	3898,50
Zone 4			13,9				0,00	17,38	0,00	0,00	0,00	17,38	75,00	1303,13
Zone 5			18,6				0,00	23,29	0,00	0,00	0,00	23,29	74,00	1723,28
Zone 6	2				15,5		0,00	0,00	0,00	19,33	0,00	19,33	34,00	657,05
Zone 7		15,67					19,59	0,00	0,00	0,00	0,00	19,59	44,40	869,69
Zone 8					17,8		0,00	0,00	0,00	22,29	0,00	22,29	52,20	1163,41
Zone 9			1,91				0,00	2,39	0,00	0,00	0,00	2,39	65,00	155,19
Zone 10			22,3				0,00	27,81	0,00	0,00	0,00	27,81	38,00	1056,88
Zone 11			13,8				0,00	17,24	0,00	0,00	0,00	17,24	17,00	293,04
Zone 1				15			0,00	0,00	18,13	0,00	0,00	18,13	91,00	1649,38
Zone 2				21			0,00	0,00	25,74	0,00	0,00	25,74	176,00	4529,80
Zone 3				14			0,00	0,00	17,29	0,00	0,00	17,29	276,00	4771,35
Zone 4				17			0,00	0,00	20,91	0,00	0,00	20,91	75,00	1568,44
Zone 5				6,7			0,00	0,00	8,41	0,00	0,00	8,41	74,00	622,53
Zone 6	3			11			0,00	0,00	13,99	0,00	0,00	13,99	34,00	475,58
Zone 7				6,1			0,00	0,00	7,59	0,00	0,00	7,59	44,40	336,89
Zone 8				6,1			0,00	0,00	7,66	0,00	0,00	7,66	52,20	399,98
Zone 9				24			0,00	0,00	30,61	0,00	0,00	30,61	65,00	1989,81
Zone 10				16			0,00	0,00	19,75	0,00	0,00	19,75	38,00	750,50
Zone 11				33			0,00	0,00	41,75	0,00	0,00	41,75	17,00	709,75

Waste source	Aircraft No.	Distance to Set 1 (m)	Distance to Set 2 (m)	Distance to Set 3 (m)	Distance to Set 4 (m)	Distance to Set 5 (m)	Time on Distance to set 1 (s)	Time on Distance to set 2 (s)	Time on Distance to set 3 (s)	Time on Distance to set 4 (s)	Time on Distance to set 5 (s)	Time of disposal (s)	Frequency of disposal	Total Time of disposal (s)
Zone 1					13,6		0,00	0,00	0,00	16,95	0,00	16,95	91,00	1542,45
Zone 2					14,2		0,00	0,00	0,00	17,79	0,00	17,79	176,00	3130,60
Zone 3					11,8		0,00	0,00	0,00	14,74	0,00	14,74	276,00	4067,55
Zone 4					12,4		0,00	0,00	0,00	15,46	0,00	15,46	75,00	1159,69
Zone 5		16,51					20,64	0,00	0,00	0,00	0,00	20,64	74,00	1527,18
Zone 6	4	2,45					3,06	0,00	0,00	0,00	0,00	3,06	34,00	104,13
Zone 7		12,57					15,71	0,00	0,00	0,00	0,00	15,71	44,40	697,64
Zone 8		10,64					13,30	0,00	0,00	0,00	0,00	13,30	52,20	694,26
Zone 9					6,15		0,00	0,00	0,00	7,69	0,00	7,69	65,00	499,69
Zone 10		10,29					12,86	0,00	0,00	0,00	0,00	12,86	38,00	488,78
Zone 11					17,5		0,00	0,00	0,00	21,90	0,00	21,90	17,00	372,30
Zone 1				15			0,00	0,00	18,24	0,00	0,00	18,24	91,00	1659,61
Zone 2				16			0,00	0,00	20,44	0,00	0,00	20,44	176,00	3597,00
Zone 3						12	0,00	0,00	0,00	0,00	15,15	15,15	276,00	4181,40
Zone 4						12	0,00	0,00	0,00	0,00	15,53	15,53	75,00	1164,38
Zone 5						20	0,00	0,00	0,00	0,00	24,46	24,46	74,00	1810,23
Zone 6	5			16			0,00	0,00	20,44	0,00	0,00	20,44	34,00	694,88
Zone 7						24	0,00	0,00	0,00	0,00	29,94	29,94	44,40	1329,23
Zone 8						21	0,00	0,00	0,00	0,00	26,80	26,80	52,20	1398,96
Zone 9						6,1	0,00	0,00	0,00	0,00	7,63	7,63	65,00	495,63
Zone 10				16			0,00	0,00	19,75	0,00	0,00	19,75	38,00	750,50
Zone 11						17	0,00	0,00	0,00	0,00	21,68	21,68	17,00	368,48

Appendix No. 12

Scenario 2. Solution 2 – five aircrafts, five waste bin sets. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	9	11,75	20,25	3,63	11,5	10	2,25	6,83	4,76	4,76	0	84,73	120
	Dirty rags	9,25	16	24,25	8,5	15	3,5	25,5	22,5	13,25	13,5	0	151,25	240
	Used filters	0	0	0,13	0,38	0,76	0	0	1	0,13	0	0	2,4	60
	Metal	0,38	0,13	0,38	0,38	0,76	0,26	0,15	0,16	0,5	0,26	0	3,36	60
	Rubber	5	6	6,75	4,75	9,5	5	6	5	2,75	8,5	0	59,25	120
	Chemicals	0,5	0,5	1	2	4	1	2,25	1	0,25	0,5	0	13	60
2	Paper/plastic	0	11,75	20,25	3,63	11,5	10	6,75	6,39	6,83	4,76	0	81,86	120
	Dirty rags	0	16	24,25	8,5	7,5	0	0	0	13,25	6,75	1,5	77,75	120
	Used filters	0	0	0,13	0,38	0,38	0	0	0	0,13	0	0	1,02	60
	Metal	0	0,13	0,38	0,38	0,38	0	0	0	0,5	0,13	0,13	2,03	60
	Rubber	0	6	6,75	4,75	4,75	0	0	0	2,75	4,25	2,25	31,5	60
	Chemicals	0	0,5	1	2	2	0	0	0	0,25	0,25	0	6	60

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	2	3	4	5	6	7	8	9	10	11		
3	**Paper/plastic**	18	23,5	20,25	3,63	5,75	10	2,25	2,13	6,83	2,38	2,26	96,98	140
	Dirty rags	18,5	23,5	20,25	5,75	7,5	3,5	8,5	11,25	13,25	6,75	3	121,75	240
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0,76	0,26	0,38	0,38	0,38	0,26	0,05	0,08	0,5	0,13	0,26	3,44	60
	Rubber	10	12	6,75	4,75	4,75	1	2	2,5	2,75	4,25	4,5	55,25	80
	Chemicals	1	1	1	2	2	1	0,75	0,5	0,25	0,25	0	9,75	60
4	**Paper/plastic**	18	11,75	20,25	3,63	0	5	0	2,13	6,83	2,38	1,13	71,1	120
	Dirty rags	18,5	16	24,25	8,5	0	1,75	0	11,25	13,25	6,75	1,5	101,75	140
	Used filters	0	0	0,13	8,5	0	0	0	0,5	0,13	0	0	9,26	60
	Metal	0,76	0,13	0,38	0,38	0	0,13	0	0,5	0,5	0,13	0,13	3,04	60
	Rubber	10	6	6,75	4,75	0	2,5	0	2,5	2,75	4,25	2,25	41,75	80
	Chemicals	1	0,5	1	2	0	0,5	0	0,5	0,25	0,25	0	6	60

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	2	3	4	5	6	7	8	9	10	11		
5	Paper/plastic	0	0	20,25	3,63	5,75	0	2,25	2,13	6,83	0	1,13	41,97	80
	Dirty rags	0	0	20,25	3,63	7,5	0	8,5	11,25	13,25	0	1,5	65,88	120
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0	0	0,38	0,38	0,38	0	0,05	0,08	0,5	0	0,13	1,9	60
	Rubber	0	0	6,75	4,75	4,75	0	2	2,5	2,75	0	2,25	25,75	60
	Chemicals	0	0	1	2	2	0	0,75	0,5	0,25	0	0	6,5	60

Appendix No. 13

Scenario 2. Solution 1 – one aircraft, one waste bin set

Waste source	Aircraft No.	Distance to Set 1	Time on distance (s)	Time of disposal (s)	Frequency	Total Time(s) of disposal
Zone 1	1	22,98	28,73	28,73	91	2613,975
Zone 2		11,11	13,89	13,89	176	2444,2
Zone 3		9,68	12,10	12,10	276	3339,6
Zone 4		12,03	15,04	15,04	75	1127,813
Zone 5		17,28	21,60	21,60	74	1598,4
Zone 6		26,57	33,21	33,21	34	1129,225
Zone 7		17,49	21,86	21,86	44,4	970,695
Zone 8		17,66	22,08	22,08	52,2	1152,315
Zone 9		3,56	4,45	4,45	65	289,25
Zone 10		20,3	25,38	25,38	38	964,25
Zone 11		15,59	19,49	19,49	17	331,2875

Appendix No. 14

Scenario 2. Solution 1 – one aircraft, one waste bin set. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
1	**Paper/plastic**	9	11,75	20,25	3,63	5,75	10	2,25	6,83	4,76	2,38	1,13	77,73	140
	Dirty rags	9,25	16	24,25	8,5	7,5	1,75	8,5	11,25	13,25	6,75	1,5	108,5	140
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0,38	0,13	0,38	0,38	0,38	0,13	0,05	0,08	0,5	0,13	0,13	2,67	60
	Rubber	5	6	6,75	4,75	4,75	2,5	2	2,5	2,75	4,25	2,25	43,5	80
	Chemicals	0,5	0,5	1	2	2	0,5	0,75	0,5	0,25	0,25	0	8,25	60

Appendix No. 15

Scenario 2. Solution 3 – one aircraft, one waste bin set

Waste source	Aircraft No.	Distance to Set 1	Time (s)	Frequency	Time of disposal (s)
Zone 1	1	14,88	18,60	91,00	1692,60
Zone 2		19,67	24,59	176,00	4327,40
Zone 3		12,93	16,16	276,00	4460,85
Zone 4		15,88	19,85	75,00	1488,75
Zone 5		5,3	6,63	74,00	490,25
Zone 6		12,4	15,50	34,00	527,00
Zone 7		17,95	22,44	44,40	996,23
Zone 8		13,6	17,00	52,20	887,40
Zone 9		23,44	29,30	65,00	1904,50
Zone 10		5,84	7,30	38,00	277,40
Zone 11		31,86	39,83	17,00	677,03

Appendix No. 16

Scenario 2. Solution 3 – one aircraft, one waste bin set. Choosing waste bin capacity

Waste disposal set	Type of bin	Generated waste in Zones (l):											Total bin capacity	Choosen bin capacity
		1	2	3	4	5	6	7	8	9	10	11		
1	Paper/plastic	9	11,75	20,25	3,63	5,75	10	2,25	6,83	4,76	2,38	1,13	77,73	140
	Dirty rags	9,25	16	24,25	8,5	7,5	1,75	8,5	11,25	13,25	6,75	1,5	108,5	140
	Used filters	0	0	0,13	0,38	0,38	0	0	0,5	0,13	0	0	1,52	60
	Metal	0,38	0,13	0,38	0,38	0,38	0,13	0,05	0,08	0,5	0,13	0,13	2,67	60
	Rubber	5	6	6,75	4,75	4,75	2,5	2	2,5	2,75	4,25	2,25	43,5	80
	Chemicals	0,5	0,5	1	2	2	0,5	0,75	0,5	0,25	0,25	0	8,25	60