A Heuristics and Discrete Event Simulation for Optimized Layout Design in Agricultural Machinery Maintenance - A Case Study of Wereta International Business Plc.

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Approval Page

As member of the board of examiners of the final Master's degree thesis paper presentation, we certify that we have read and evaluated the thesis paper prepared by Fitsumberhan Hailemeskel with the title **"A Heuristics and Discrete Event Simulation for Optimized Layout Design in Agricultural Machinery Maintenance - A Case Study of Wereta International Business Plc."** and recommend that it has been accepted as fulfilling the thesis paper requirement for the degree of master of science in Industrial Engineering.

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DECLARATION

I hereby declare that this thesis, entitled "Layout Modeling and Optimization of an Agricultural Machinery Maintenance Facility using Discrete Event Simulation: A Case of Wereta International Business Plc.," is the result of my own work and research, except where otherwise acknowledged. This work has not been submitted previously, in whole or in part, to qualify for any other academic award. All sources of information and data used have been duly acknowledged.

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Fitsumberhan Hailemeskel Date

(Candidate)

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

__________________________ __________________________

Dr. Ameha Mulugeta Date

(Thesis Advisor)

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

WIB: -	Wereta International Business Plc.
PDI: -	Pre-delivery Inspection
CORELAP: -	Computerized Relationship Layout Planning
ALDEP: -	Automated Layout Design Programme
PLANET: -	Plant Layout Analysis and Evaluation Techniques
COFAD: -	Computerized Facilities Design
CRAFT: -	Computerized Relative Allocation of Facilities Technique
DES: -	Discrete Event Simulation
ARC: -	Activity Relationship Chart
TCR: -	Total Closeness Ratio
PR: -	Placement Rating
WIP: -	Work in Progress

Abstract

Agricultural machineries play a vital role in agricultural processes and help in the production of food and non-food items. The efficient layout of agricultural machinery maintenance facilities is crucial for minimizing process times and maximizing throughput. This paper deals with the development and optimization of an agricultural machinery maintenance facility using discrete event simulation considering Wereta International Business Plc.'s agricultural machinery maintenance facility layout as a case. The development of the facility layout is done in a way that introduces flexibility of departments and also that combines the different services given in the facility, maintenance, training (customer & staff) and pre-delivery inspection processes.

The research tries to construct a new facility layout that decreases the travel distance, considers the relationship between departments using the CORELAP facility layout construction method. The newly constructed facility layout has been optimized using facility layout improvement technique, CRAFT (excel add-in) to further enhance the optimality of the facility layout by enhancing the material flow between departments to minimize the material handling cost.

Finally, an improved facility layout, with 15 departments that include main and supporting facilities and also combines the services and training facilities is developed. The proposed facility layout reduces that has been constructed from scratch and then optimized decreases the distance traveled between departments by 2,015.11 meter (a reduction of 33.66%) and the total monthly material handling cost by 531,093.14 Birr per month (a reduction of 86.85%). The entity output of the existing system is 40 units and for the proposed layout, the entity output is 67, an increase by 67.50%. Also, the system output from the existing simulation model is 125.30 units and the proposed layout simulation modeling system output increased by 58.85% to 199.04 units.

Key Words: Agricultural Machinery, Maintenance Facility Layout, Layout Optimization, Discrete Event Simulation

Chapter One

1.1 Introduction and Background

1.2 Introduction

Agricultural mechanization is "the application of mechanical technology and increased power to agriculture, largely as a means to enhance the productivity of human labor and often to achieve results well beyond the capacity of human labor" (Ayele, 2021).

Agricultural machines are mostly maintained in any space available at the farm and if the case is far more serious, it will be taken to a maintenance facility. But, inefficiency in the maintenance facility/workshop, especially in developing countries will lead to increased maintenance cost, unsafe environment, delays in maintenances and customer dissatisfaction. In the modern era, mechanically powered agricultural machines like tractors and combine harvesters are being used in the harvest and post-harvest activities of the agricultural production process, making agricultural mechanization one of the main contributors influencing the agriculture industry. Due to the lack of proper maintenance inputs and maintenance plans, the failure rate of agricultural machinery in developing countries is higher than in developed countries (Mishra & Satapathy, 2021).

One of the factors that determine the smooth operation of the different mechanical machines is the proper maintenance of the machinery and the availability of a proper maintenance facility/workshop. The agricultural machinery maintenance workshop is a critical part of any agricultural operation. It is responsible for keeping the machinery running smoothly and efficiently, which is essential for productivity and profitability.

The efficiency and effectiveness of the agricultural machinery's maintenance facility depends on several conditions including the safety of the maintenance operation, availability of trained mechanics, availability of machines and equipment's, smooth workflow and a well-designed facility layout.

"Facility layout is the arrangement of operations, machinery and spaces and the correlation between them". Layout planning is the art of determining and deciding the connection of personnel, the facility location, and the site in relation with the type of workflow, process and service that the facility is providing (Mebrat et al., 2020).

The facility layout is one of the major aspects of any maintenance workshop. Facility layout deals with the placement of personnel, different machines and tools, safety of the arrangement of the facility for an effective and efficient facility (Al-Zubaidi et al., 2021).

The success of a facility's layout is determined by the physical placement of its personnel and facilities in relation to one another, as well as by how its multiple processes are distributed physically for the conversion of resources (Boby & Bibin, 2018; Zuniga et al., 2020).

This research paper aims to develop an optimized facility layout plan for the workshop using layout planning models that will minimize the distance that technicians have to travel between workstations, incorporate different infrastructures, decrease queue, decrease material handling cost and considers the relationship between departments.

1.3 Background and Justification

Like any other mechanical equipment's, agricultural machines need a proper service and maintenance to be able to perform their job with ease. Preventive, corrective, predictive maintenance and also by planning for future maintenance will help in keeping the machines in good working condition.

The lack of well-designed maintenance workshops poses several challenges. Firstly, the absence of an optimized layout hampers the overall productivity of the maintenance process. The lack of proper organization leads to difficulties in locating tools and equipment promptly, resulting in unnecessary delays during repairs. Additionally, inadequate space allocation may restrict the simultaneous servicing of multiple machines, further prolonging downtime. And all these issues leading to increased maintenance costs, unsafe environment, delays in maintenances, and customer dissatisfaction (James et al., 2020).

The efficiency and effectiveness of the agricultural machinery's maintenance facility depends on several things including the safety of the maintenance operation, availability of trained mechanics, availability of machines and equipment, smooth workflow, and a well-designed facility layout. The facility layout is one of the major aspects of any maintenance workshop. Facility layout deals with the placement of personnel, different machines and tools, safety of the arrangement of the facility for an effective and efficient facility (Al-Zubaidi et al., 2021).

Agricultural machinery maintenance facilities may face challenges related to inefficient layouts that hinder workflow efficiency, increase travel distances, and result in resource wastage. The reasons for layout optimization of any facility include the need to improve productivity, reduce material handling costs, and create a sustainable process. Furthermore, the optimization of facility layout is essential for creating a workplace with high frequency and logical relationships between areas, allowing for the quickest material flow at the lowest cost and with the least amount of handling (Mishra & Satapathy, 2021).

Wereta International Business Plc. is a private company with various business ventures in dealership (Volvo trucks, Volvo construction equipment's and CASE IH agricultural machineries), manufacturing, mining, export and import. Wereta International Business Plc. offers different agricultural machineries and implements with different range. As an official dealer for CASE IH agricultural machineries, the company has an agricultural machinery maintenance facility around Kality.

Figure 1: WiB agricultural Machinery Maintenance Facility

The overall area of the workshop is about 2000 m^2. The area division of the workshop is as follows:

Table 1: Workshop Area Division

No.	**Description**	**Area in m^2**
1	Office Building	160 m^2
2	Maintenance area	200 m^2
3	Break room (café)	30 m^2
4	Changing room	50 m^2
5	Storage (Truck and machinery tires)	135 m^2
6	Consumable Storage	50 m^2
7	Parking for new machineries (enough for parking 15 - 25, depending on size)	480 m^2
8	Machinery loading/unloading area	40 m^2
9	Space in front of maintenance area (used for maintenance when the shop is full and for PDI operations)	200 m^2
10	Different corridors, guard houses and areas unsuitable for maintenance and parking	600 m^2

The workshop has an office building (3 offices and restroom), maintenance area (including overhaul and garage pit), break room (café), 2 storage areas for machinery materials and tire storage, parking for new machineries, area for loading/unloading machineries and locker Rooms and Changing Areas.

Like most maintenance facilities in Ethiopia, it was not designed considering even the less simple layout development techniques. Due to the limited capacity of the workshop (at a time a maximum of 3 maintenance and 2 PDI operations can be done) a queue is formed (10-15 maintenance requests in and out of the workshop) and leading to work inefficiency and customer dissatisfaction.

According to job orders of the past three years (2021,2022) and 2023 (up to august), it can be seen that the amount of maintenance requested was 1,340, out of which 1,018 maintenance requests were processed, leaving 322 unprocessed requests.

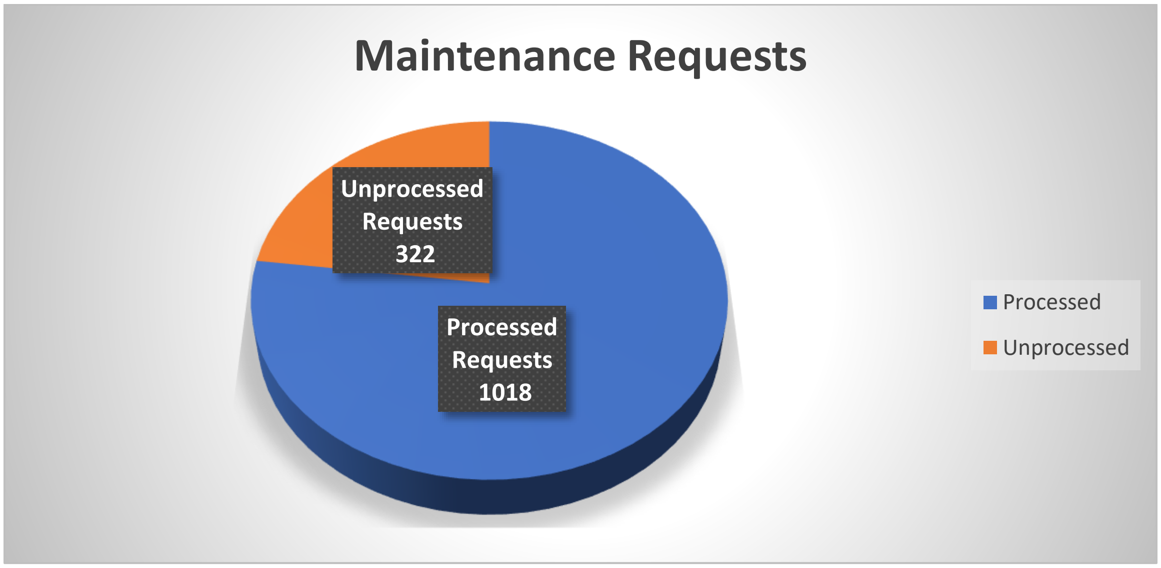


Figure 2: Maintenance Request

When it comes to maintenance, CNHI (supplier of CASE IH Machineries) has a recommended standard time for the period needed to diagnose and maintain different components of the agricultural machine (available on the CNHI's dealer portal). As it can be seen from the work register of the facility, the maintenance times are much higher in the workshop.

The workshop is also responsible for the Pre-Delivery Inspection and storage of agricultural machineries. The workshop technicians follow a Pre-Delivery Inspection form supplied by the supplier CASE IH to check if the machineries are in the desired state, to check for the different features of the machinery and to check for any physical damages. The PDI form contains 16 major areas of inspection with a total of 122 tasks to be done starting from engine to paint and also requires conducting a drive test and moving the machinery to conduct the different inspections (Appendix 1). The standard time for PDI is 4 hrs for one technician, but the job orders (2021, 2022 & 2023) show that it takes more than 6 hours for 2 technicians. This is mainly due to the time wasted through material and tool retrieval and failure to allocate a designated area for PDI operations (especially for drive tests), thus creating queues in the PDI operation.

The need for the layout modeling and optimization of an agricultural machinery maintenance facility arises due to the above-mentioned issues and problems in the agricultural machinery maintenance facility of Wereta international business plc. And also, the company's mission to provide a state-of-the-art maintenance facility with skillful and knowledgeable maintenance staff is another reason that motivated the research.

1.4 Problem Statement

Wereta International Business Plc.'s current agricultural machinery maintenance facility has 3 spaces for major overhaul and replacement, routine maintenance and services, tire maintenance, lubrication and so on. And there are 2 garage pits for transmission, differential and other basic maintenance procedures. In some cases, machineries waiting for insurance claim and for an order of a major machinery part will occupy maintenance areas for a long period of time, leading to space shortage.

The mission of Wereta is ‘‘to establish for long-term business relationship with its suppliers and customers by dealing with high quality products and providing efficient services through state-of-the art facilities, highly skilled motivated workforce and work methods. Wereta works to achieve sustainable returns to its shareholders and satisfaction of its employees.’’

Looking at Wereta's mission, one focus area is providing efficient services through state-of-the art facilities, highly skilled motivated workforce and work methods. One way of providing an efficient service in a maintenance facility is through the delivery of a proper and regular training for the employees and service providers. In a maintenance facility, training is important for skill development, safety enhancement, equipment familiarization, efficient workflow, and continuous improvement. To have a state-of-the-art facility and increase customer satisfaction and employee technical knowledge, the workshop should have proper infrastructure for supporting facilities but Wereta's workshop is missing:

Training facility, tools room (the technicians are given tool boxes that are stored in the dressing room and have to carry it around when doing maintenance or PDI), spare parts storage (spare parts are stored at the sales office, about 300 meters from the workshop), technician and customer training and development facility, machinery cleaning and washing facilities, area for agricultural implements assembly (assembly is done in another compound around 350 meters away with a monthly rental cost of 110,000 birr), pre-delivery inspection facility (currently carried out in any free space available in the workshop), and metal and fabrication shop (according to the financial reports an average of 200,000 birr is spent on outsourcing for metal work).

And the following are infrastructures that are available in the maintenance facility but need to be improved: locker rooms and changing areas, break rooms and rest areas for employees and customers, and parking and inspection area for newly arriving agricultural machineries.

Also, looking at the layout Proximity, the close proximity of the office to the maintenance area (the office is next to the maintenance area, creating a disturbance in the work environment).

According to the study done by the workshop management in 2022 (Lemma, Workshop Performance) on the workshop operation, including workshop performance, efficiency of technicians, and efficient working hours/day of a technician and number of technicians, the calculated data for the workshop performance is **65%**, Efficiency of technicians **71.4 %** and Efficient working hours/day for technicians – **5.2/8hrs (a waste of 2.8 hrs/day).**

According to WIB job orders and repair time schedule (for maintenance done in the workshop) of the years 2021, 2022 and 2023, it can be seen that the standard time used by the company is more than what is recommended, leading to queues in the maintenance and PDI operation and also, leading to customer dissatisfaction, especially during peak farming and harvesting seasons.

The table below compares the time it took for maintenance of a certain job at Wereta's maintenance workshop against the suppliers recommended maintenance time for few work orders:

Table 2: Maintenance Time Comparison

No.	Job Description (Service Work)	CNHI Standard Maintenance Time	Maintenance Time at Wereta's Workshop
1	Cylinder Block (Engine Overhaul)	58 h 12 min	81 h 29 min
2	Rocker Arm Assembly with Control	3 h	4 h 12 min
3	Replacement of all Piston Rings	22 h	30 h 48 min
4	Crankshaft	33 h 12 min	48 h 28 min

5	Valve Guide	20 h	28 h
6	Injector Assembly	5 h	7 h

And due to this limited capacity of the facility, failure to meet standard maintenance time, the absence of supporting facilities, wasted time and overall workshop performance, the facility is unable to maintain an efficient operational performance.

1.5 Research Question

This research strives to achieve the aforementioned problems by addressing the following research questions:

RQ 1: How does the current layout of agricultural machinery maintenance facility impact the workflow and efficiency of maintenance operations?

RQ 2: What layout optimization techniques, configurations and operational strategies can be explored to optimize the utilization of space, resources, and workflow in the agricultural machinery maintenance facility?

RQ 3: How can discrete event simulation modeling be effectively applied to model and analyze the layout of an agricultural machinery maintenance facility?

1.6 Objective of the Study

1.6.1 General Objective

To develop a facility layout that is a combination of all the services (Maintenance, PDI, and Training), optimize its performance using heuristic approach and use Discrete Event Simulation for validation in Wereta International Business Plc.'s agricultural machinery maintenance facility.

1.6.2 Specific Objectives

A. To evaluate the impact of the current layout on the workflow and efficiency of maintenance operations in an agricultural machinery maintenance facility.

B. To identify and evaluate layout optimization techniques, configurations and operational strategies considering factors such as travel distance, interdepartmental relationship, flow matrix and material handling cost.

C. To assess the effectiveness of discrete event simulation modelling of the facility layout in representing and analyzing by comparing simulation results with real-world data and observation.

1.7 Scope and Limitation of the Study

1.7.1 Scope

The study is conducted at Wereta International Business Plc's agricultural machinery maintenance workshop. The research focuses on the design and development of an optimized workshop layout using Discrete Event Simulation. Arena student version Software is used for the Discrete Event Simulation.

Different layout development and optimization techniques are available to use and the study does not attempt to use all. CORELAP technique has been used for the construction and development of the facility layout, and CRAFT excel add-in program has been used for the improvement and optimization of the CORELAP layout output.

The research doesn't consider external factors like technology changes, regulations or industry practices that may impact the facilities performance.

This study is limited by the fact that it is conducted in a single workshop. The findings of the study may not be generalizable to other workshops.

1.7.2 Limitation of the Study

There are different layout optimization techniques with each having their own varying strengths, weaknesses and assumptions. The selected techniques may not capture all the possible solutions or may have limitations in handling complex constraints, thus impacting the result.

Arena software student version, will be used for the Discrete Event Simulation and to test and validate the proposed facility layout. Arena student version has limitations on the size and complexity of models one can simulate, build and wider range of advanced features are not available in the student version. These might include optimization tools, custom programming functionality, integration with other software, and advanced statistical analysis capabilities. In the case of this limitations, counter actions like simplifying the model, optimizing simulation parameters, using aggregate data to reduce complexity and limiting animation and visualization will be employed for proper use of the software's limited capacity.

This study is limited by the fact that it will be conducted in a single workshop. The findings of the study may not be generalizable to other workshops.

1.8 Significance of the Study

The research has a number of importance, relevance and potential impact on the operation of an agricultural machinery maintenance facility. As layout modeling and optimization is one way to improve the performance of any facility, this study is significant in improving the overall productivity, enhancing maintenance performance, reducing cost, and improving working conditions (safety).

The research provides practical recommendations and guidelines based on the findings, empowering Wereta International Business Plc. to make informed decisions for layout improvement, maintenance process optimization, and resource utilization.

The research also contributes to the industrial Engineering body of knowledge as a literature for related studies and will also pave the way for future research in the agricultural mechanization and maintenance sector.

1.9 Organization of the paper

This research on Layout modeling and optimization of an agricultural machinery maintenance facility using discrete event simulation has five main chapters. The first chapter, introduction and justification, covers introduction, background and justification, problem statement, research questions, objective of the study, significance of the study, scope and limitation of the study and finally the organization of the study. The second chapter deals with literature survey on maintenance facilities, facility layout planning, simulation models and layout optimization. The third chapter, methodology, covers research design, data collection methods and data analysis. The fourth chapter deals with the data collection, analysis, results and discussion. And finally, the fifth chapter deals with conclusion, recommendation.

Chapter Two

2. Literature Review

2.1 Introduction

This literature review examines different researches on maintenance facilities, facility layout design models, discrete event simulation and layout optimization tools.

The review focuses on the overall overview of the methodologies, approaches, and factors considered in optimizing facility layouts, as well as the benefits and challenges associated with implementing DES-based solutions. Key topics explored include maintenance facilities, facility layout modeling and improvement techniques, and the use of DES in modeling maintenance processes, layout design considerations, optimization algorithms, performance metrics, and case studies.

By analyzing the existing literature, the review aims to contribute to a deeper understanding of the current state of research in this field and provide valuable insights for improving the efficiency and effectiveness of maintenance facilities through layout modeling and optimization using discrete event simulation.

2.2 Literature Methodology

The objective of this literature review is to analyze existing studies related to maintenance facilities, facility layout development and improvement, simulation models and in general to contribute to the academic literature by analyzing existing knowledge and aiding future researches in this field. A comprehensive search was conducted using electronic databases Science Direct, Elsevier, Emerald, Frontiers, IJASRE, De Gruyter and IEEE. For this research, a total of 41 literatures have been reviewed.

The literature reviewed has been limited to studies published between the years 2018 to 2023. The review area for the literature review included (1) maintenance facilities, (2) facility layout development and improvement, (3) simulation models, and (4) optimization techniques. The results obtained from the selected studies were synthesized and summarized. The limitation of the review is the exclusion of non-English studies, which may limit the generalizability of the findings.

2.3 Maintenance Facilities

Maintenance is "The combination of all technical, administrative and managerial actions, during the life-cycle of an item intended to retain it in, or restore it to, a state in which it can perform a required function". In the past, maintenance has been thought of unnecessary, as it incurred cost but the return couldn't be seen or quantified. In some cases, maintenance costs were in the range of 15%-40% of the total production cost (Lundgren et al., 2020).

Maintenance facilities play a crucial role in maintaining the functionality, reliability, and safety of equipment and facilities in various sectors. In the hotel sector, a structured maintenance plan is necessary to ensure the proper functioning of equipment, energy efficiency, and overall cost management. In the context of railway maintenance, it is not just about keeping facilities in their current state but also includes improvement, functionality, and replacement to ensure safety and stability. In the automotive sector, maintenance is performed for the fulfilment of safety and performance measures, to prevent failure, to meet with manufacturer guidelines, to increase the resale value, reduce operation cost and to contribute to customer satisfaction (Wijesinghe & Mallawarachchi, 2019).

In the machinery and vehicle maintenance industry, facilities try to establish a state-of-the-art maintenance facility with at least the basic requirements. In the industry, state-of-the-art refers to the availability of a skilled workforce, efficient layout and design, offering comprehensive services, high standard for safety and compliance and having different facilities that support the main operation of the facility. But these constraints are often overlooked in the development and construction of maintenance facilities (Chen et al., 2023; Holik, 2019; Liu et al., 2023).

James et al. (2020) states that the type of maintenance needed for a vehicle/machinery is "inspection, general repair and replacement of major assemblies, lubrication, fluid changes, tune-ups, tire rotation, painting, welding, repair upholstery, testing, cleaning, storage and retrieval of parts, fabrication of minor parts, accident repair and overhauls". And these maintenance requirements will vary according to the type of the maintenance facility and the type of machinery or vehicle.

And specifically looking at agricultural machinery maintenance, the lack of skill for the maintenance and fault diagnosis of agricultural machineries arises from the absence of continuous training on current and future maintenance procedures and continuous improvement in the field (Chen et al., 2023). Agricultural machineries are mostly susceptible to failure and malfunction during the harvest season. Since the maintenance facilities are distant from the agricultural production area, hence requiring high cost for their transport and maintenance. One problem arising here is that the maintenance facilities are not easily accessible and are traditional fixed maintenance facilities (Hu et al., 2020).

2.4 Facility Layout Planning

According to Mebrat et al. (2020) "Facility layout is the arrangement of operations, machinery and spaces and the correlation between them". Layout planning is the art of determining and deciding the connection of personnel, the facility location, and the site in relation with the type of workflow, process and service that the facility is providing.

Facility layout planning has been used in various application areas and industries like manufacturing, warehouse and logistics, and service facilities. In manufacturing, facility layout planning is mostly used for the optimization of the existing layout to reduce bottlenecks, improve workflow and minimizing material handling. Another application area is the warehouse and logistics, in this case, facility layout planning is used for the optimal placement of storage areas, decrease travel distance and material handling equipment's for the increased workflow and customer satisfaction. The healthcare industry is another application area where facility layout planning is used for the design of patient flow, placement of equipment and supporting facilities, optimization of the arrangement of treatment rooms for reducing service waiting time for a patient improved patient experience and an improved overall service. Finally, in service giving facilities, facility layout planning is used for arrangement of aisles, storage areas and for the improvement of the overall efficiency and effectiveness of the facility (Amaral, 2020; Cubukcuoglu et al., 2021; Mebrat et al., 2020).

Facility layout planning involves the improvement of workstations, equipment and personnel arrangement, and resource utilization in order to enhance and improve bottlenecks, material handling cost, workflow, and other elements of the industry/facility (Boby & Bibin, 2018; Rifai et al., 2023).

For the development of an optimum facility layout, different tools can be used in conjunction with facility layout planning depending on the objective or the requirement of the facility. Engineers can use computer aided design (CAD), simulation software, lean principles, value stream mapping, optimization techniques, and ergonomics analysis in combination with facility layout planning to develop a layout that that is optimum and aids in efficient productivity (Boby & Bibin, 2018; Burggräf et al., 2021).

In conclusion, key benefits like workflow optimization, space utilization, resource allocation ergonomics and safety, cost reduction and flexibility can be achieved by implementing facility layout planning in different industries or facilities.

2.5 Facility Layout Problems

The efficient facility layout design and optimization of maintenance facilities play a crucial role in ensuring the smooth operation of the maintenance facility. The layout and configuration of these facilities can significantly impact their operational effectiveness, resource utilization and overall productivity (James et al., 2020; Singh & Ingole, 2019).

Facility layout problems are those problems that affect the performance of a facility and arise due to the non-optimal placement of different elements of the facility. Layout problems address and are applicable in different production and service giving facilities like warehouses, banks, airports and so on. With each facility having its own specific and distinct characteristics in the need for a facility layout development or improvement objective (Guan et al., 2019; Liu & Liu, 2019).

An effective facility layout design considers the problems that will impact and affect the production, manufacturing, or overall processes (Al-Zubaidi et al., 2021). The effectiveness of the layout of the facility is determined by the physical arrangement of an operation's personnel and facilities, as well as how its many processes are physically distributed for the conversion of resources (Zuniga et al., 2020).

As the application areas and distinct characteristics of the problems differ, researchers are divided on the definition of layout problem, as static and dynamic layout problems. In static layout problem, the product is fixed and is applicable in facilities with a large size product and dynamic layout problems are for those facilities with a wide range of products or services and a variable material flow (Pérez-Gosende et al., 2021).

2.6 Layout Development Techniques

Layout planning models and algorithms are used in various fields, such as manufacturing, logistics, and facility design, to optimize the arrangement of physical spaces, resources, and activities within a given environment. The aim is to improve efficiency, minimize costs, and enhance overall performance (Rifai et al., 2023).

Currently, various types of plant and facility layout construction and reconstruction algorithms are used, CORELAP (Computerized Relationship Layout Planning) and ALDEP (Automated Layout Design Programme) are used for constructing the layout from scratch, and algorithms like CRAFT and COFAD (Computerized Facilities Design) were employed to try to make it better with trading facilities (Boby & Bibin, 2018; Rifai et al., 2023; Rudolf & Martina, 2019).

2.6.1 Computer Aided Layout Planning

Computer aided layout planning refers to the different tools and computer software that are used for the development and improvement of a facility layout.

Currently, different plant and facility layout construction and reconstruction algorithms are used, both for layout construction and layout improvement. CORELAP (Computerized Relationship Layout Planning) (Lee, and Moore 1967), ALDEP (Automated Layout Design Programme) (Seehof, and Evans 1967) and PLANET (Plant Layout Analysis and Evaluation Techniques) (Deisenroth, and Apple 1972) are construction type layout development techniques and are used for constructing the layout from scratch. Algorithms like CRAFT (Computerized Relative Allocation of Facilities Technique) (Armour, and Buffa 1963) and COFAD (Computerized Facilities Design) (Tompkins, and Reed 1973) are layout improvement techniques employed to try to make it better with trading facilities (Burggräf et al., 2021).

2.6.1.1 CORELAP

The CORELAP (Computerized Relationship Layout Planning) algorithm is used to develop a layout design from scratch and it doesn't require the facilities existing layout (it is independent of the existing layout design). The CORELAP is used to determine and identify the total closeness ratio (TCR) of different workstation placements to develop an effective and efficient layout design (Boby & Bibin, 2018; Burggräf et al., 2021).

2.6.1.2 ALDAP

ALDEP (Automated Layout Design Program), developed by Seehof and Evans is a construction-type layout planning method to create a layout in which departments with high ranking are put together (Rifai et al., 2023).

2.6.1.3 CRAFT

CRAFT (Computerized Relationship Allocation of Facilities Technique) (Buffa et al., 1964) is one of the most used facility layout improvement method for obtaining the optimum and best arrangement of a facility layout. Layout improvement in CRAFT is done by the iterative process of switching departments to check for different configurations and find the best layout. The interchange between departments is applicable if and only if, the departments have adjacent borders or equal area. CRAFT uses from-to-chart, cost matrix, distance between departments and an initial layout as an input data (Burggräf et al., 2021; Rudolf & Martina, 2019).

In summary, when it comes to facility layout construction, the CORELAP (Computerized Relationship Layout Planning) algorithm is preferred from the other types of layout planning models, because it is used to develop a layout design from scratch and it doesn't require the facilities existing layout (it is independent of the existing layout design). The CORELAP is used to determine and identify the total closeness ratio (TCR) of different workstation placements to develop an effective and efficient layout design which helps in the placement of the different departments in a facility layout and contributing to the optimality of the facility layout (Boby & Bibin, 2018; Hanum, 2021; Wibisono & Wilasto, 2023).

2.7 Simulation Models

In the modern world, manufacturing facilities are becoming more sophisticated in terms of the technology they use. And in this new age of technology, Engineers are expected to use more advanced and computerized tools to design, develop, and validate the proposed solutions. For such complex systems, simulation is used for creating a model that imitates real-world systems while considering time and changing conditions into account to help as a problem-solving methodology for engineering problems (Zuniga et al., 2020).

There are several simulation models that are used to represent real world models and also used for validation of a proposed solution.

Geostatistical simulation models, also known as stochastic simulation models, are used in modeling spatial patterns in order to determine uncertainty and the spatial variability of the observed real-world data. Geostatistical simulation is grouped in three, object- based modeling, two-point stochastic simulation, and multiple-point simulation, depending up on the complexity of the model and the real-world data gathered. The variables that are required to be determined in a geostatistical simulation modeling are, continuous variables, categorical variables, and objects with different shapes. Mostly, geostatistical simulation models are mostly used in the earth science fields (Zakeri & Mariethoz, 2021).

Discrete event simulation is a type of simulation modeling and analysis method used to examine a system behavior that have connected components and whose states change at discrete points in time. Discrete event simulation takes different factors (decision variables) to check and calculate the key performance indicators of the system. Discrete event simulation can be used to model a system as a series of interconnected events to analyze the performance indicators of a system, test different configurations and scenarios, and validate the proposed solution and for the overall optimization the given objective. Making it the most preferred tool for the understanding, analyzing and optimizing complex systems (Cubukcuoglu et al., 2020; De Raedt et al., 2020; Trigueiro de Sousa Junior et al., 2019).

Agent-based simulation is used to model individual entities. Used to model micro-level operational processes and capture cognitive aspects of decision making in behavioral operations research (Mourtzis, 2019).

Another simulation model that has highly gained popularity and mostly used by Engineers is hybrid simulation model that is a combination of two or more simulation modeling methods. With an application area in healthcare, supply chain management and manufacturing, hybrid simulation model is used to tackle complex problems, mostly with the combination of DES and system dynamics (Brailsford et al., 2019).

When dealing with layout design modeling methods, Engineers use simulation as a way or method to test and validate the proposed design of the facility layout. The simulation method mostly used when testing and validating a proposed layout is discrete event simulation. DES is used to model events that occur at a specific time, like arrival, departure and resource allocation. DSE also allows for dynamic representation, performance evaluation and flexibility, making it the ideal simulation model to validate an agricultural machinery maintenance facility layout development and optimization.

In summary, there are different simulation software for the modeling and simulation of real-world processes. AnyLogic is one simulation software that is used for modeling of discrete event, system dynamics and more complex system analysis. Arena simulation software is mainly used for modeling and analyzing the performance and process flows of systems. Therefore, based on the objective, which is to analyze process time and throughput, and also due to its strong focus on DSE, visualization & animation, flow chart-based interface, statistical reporting and ease of use, Arena software student version is used for the Discrete Event Simulation and validation of the facility layout.

2.8 Layout Optimization

Optimization is the activity of enhancing and increasing the effectiveness and efficiency of a given objective. When specifically talking about facility layouts, optimization refers to an optimum placement of material, equipment and utilization of space. This is done by considering the relationships that exist between these elements and identifying the layout that maximizes productivity and minimizes costs. Traditional facility layout approaches prioritize optimization before simulation analysis, while more recent studies suggest running simulation models prior to optimization for more realistic layouts. The choice of approach depends on the objectives of the layout study and the characteristics of the system under consideration (Han et al., 2021; Liu & Liu, 2019).

In some cases, a facility layout needs to be optimized to address issues like operational efficiency, resource utilization, downtime reduction, safety & ergonomics, and flexibility. The lack of suitable methodology for designing an optimal layout, the lack of focus on the data, resources required and the limitation of the traditional layout construction and improvement models make the optimization process challenging (Holik, 2019; Zuniga et al., 2020).

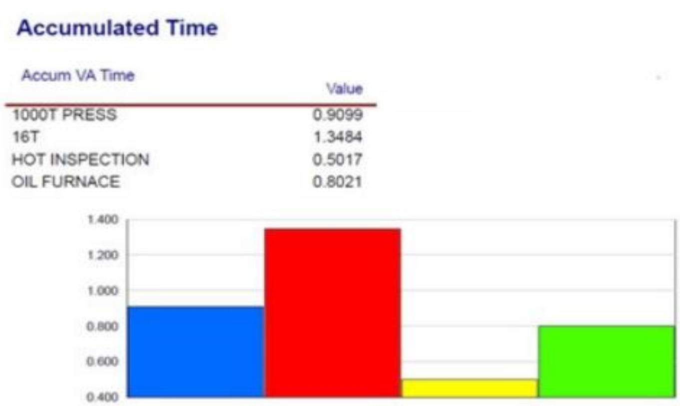
When working with facility layout development on simulation-based optimization, the first issue or challenge is its complexity and difficulty in understanding the different interactions with the different elements of the system. Also, failure to identify the optimal solution, finding the right technical people, and recent the lack of technology are other challenges of simulation-based optimization of a facility layout development (Zuniga et al., 2020).

There are other heuristic layout improvement models such as COFAD and CRAFT. And also, other mathematical, genetic, mathematical optimization with metaheuristics, and data-driven approaches for the optimization of a facility layout that will increase efficiency, increase profitability, decrease cost, decrease bottleneck and enhance workflow (Burggräf et al., 2021).

2.9 Practical Application

Binoy, Bibin, and Boby K. George conducted research that focused on optimizing the material flow in a steel forging industry by redesigning the plant layout using the CORELAP algorithm. A performance loss in the material flow pattern was identified in the forging section of the plant, which was caused by imprecise positions of machines and unnecessary material transportation.

The first case in the study involved analyzing the material flow pattern in the forging section of the plant. This analysis was done using relationship charts and closeness ratings, which identified a performance loss due to imprecise machine positions and unnecessary material transportation. To improve the results, the researchers used the CORELAP algorithm to optimize the production flow. Fifteen machines were relocated based on the algorithm's recommendations, which aimed to minimize material movement and improve the overall layout. The modified layout resulted in a value addition in the material flow pattern and an estimated improvement in productivity of 7.98%. This improvement was identified through simulation studies conducted using the software Arena, which evaluated the performance of the modified layout (Boby & Bibin, 2018).



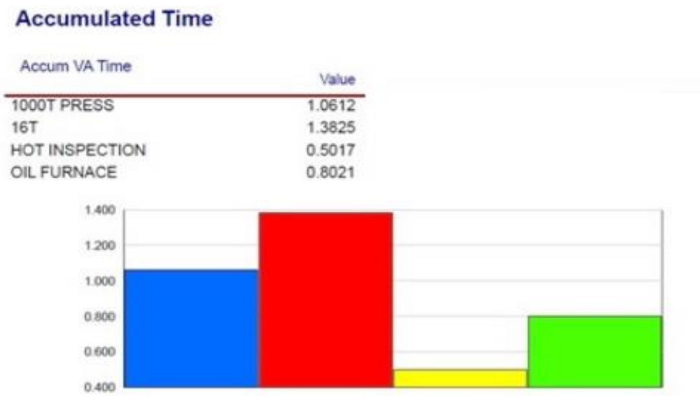


Figure 3: Time in initial and final process

(Source: Plant Layout Optimization in Steel Forging Industry by CORELAP Algorithm by Boby & Bibin)

2.10 Literature Summary

Several literatures and studies conducted in various healthcare, manufacturing, warehouse and logistics, and service giving industries have been analyzed with different focus areas like maintenance facilities, facility layout planning, facility layout problems, simulation models, and facility layout optimization techniques. Some of the literature gaps and summary for the above topics has been discussed below.

In the research by James et al. (2020), the research implies that, other than the facilities needed for maintenance, there should be enough space in a maintenance facility for supporting facilities like, tools room, rest room, locker room, part room and offices. When it comes to cost effectiveness of a maintenance facility optimization, strategically placed supporting facilities between workstations are necessary. And these facilities are pivotal in enabling efficient and effective functionality of the maintenance facility (Ferdy et al., 2023; Holik, 2019).

Out of the 11 literatures that are related specifically to maintenance facilities, only 3 were able to address these supporting facilities that are needed for the smooth, efficient and effective operation of a maintenance facility. The other research's conducted for a maintenance facility layout, these supporting facilities, space, and ambiance requirements are looked over and are not given the necessary attention in their contribution for enhanced workflow, employee motivation and enhanced maintenance time (Banerjee & Punekar, 2020; Han et al., 2020; Han et al., 2021; Hu et al., 2020; Luo et al., 2014; Mishra & Satapathy, 2021; Stern & Saltzman, 2023; Turan et al., 2021; Yao et al., 2021).

Looking at the layout improvement models, CRAFT & COFAD, both models use the existing or initial facility layout as an input for improvement. The issue here is that, as both models are dependent on the initial layout, any limitation to the development of the initial layout will affect the outcome of the improved layout. This limitation of the initial layout might come from not considering the specific needs of the facility, inefficient space allocation and inability to consider future product advancement and trends while developing the initial facility layout. One way to overcome this issue and get a layout that is close to an optimal result is by constructing the facility layout from scratch and using improvement models to further enhance it. There are very few researches in the current literatures that follow this methodology in enhancing a facility layout (Amaral, 2020; Burggräf et al., 2021; Rudolf & Martina, 2019).

Overall, the literature review tries to emphasize on the challenges and impacts of a facility layout on the work flow and effectiveness of the facility. And it also provides an overall overview of the facility layout planning, addressing its challenges, methods and applications. And it will serve as a valuable resource for future researches and decision makers to further understand the facility layout problem and explore improvements in its practice. There are other unique challenges specific to agricultural machinery maintenance facility and further researches are needed to address spatial constraints, safety considerations and integration of technology (future advancements) to the facility.

Chapter Three

3. Methodology

3.1 Introduction

The methodology section of this research encompasses various essential components, including the research design, data collection methods, data analysis techniques, and ethical considerations specific to the research conducted at Wereta International Business Plc. agricultural machinery maintenance facility.

3.2 Research Design

A mixed, Qualitative and Quantitative research design methods are utilized for the comprehensive analysis of the research.

The quantitative research method is used in data collection while analyzing the existing facility (dimensions, workstation), maintenance data, and workshop data, model development of the Discrete Event Simulation model representing the physical layout, activities, resources, and validation through comparison use a quantitative research method. Also, analysis of the data collected from the simulation and other quantitative data sources is done using this research design method.

The qualitative research method is utilized in data collection from interviews with the workshop management and maintenance personnel. This is done to get insight into the existing workflow, layout, limitations, and desired improvement of the facility. Direct observation of the maintenance facility to get a deep understanding of the workflow, the interaction between maintenance personnel and equipment, and the impact of the layout in operation also use qualitative research design method.

3.3 Data Collection

Data that is relevant to the research is collected on the current workflow of the workshop, including the movements of workers and materials, the distances between different workstations, and the frequency of tasks. The accuracy and reliability of the data is ensured by cross-referencing multiple sources and verifying information with experts.

Primary and secondary data collection methods have been presented and the data collection is from observation, interviews, a review of workshop reports, literatures and other data collection sources.

3.3.1 Ethical Consideration

The research involves the participation of the management and maintenance personnel for data collection on the state of the facility. This information and data collection process is done by informed consent and protecting the privacy and confidentiality of participants' data. Confidentiality measures are implemented to safeguard participant information. Respecting participants' autonomy, privacy, and dignity is essential throughout the research process.

3.3.2 Primary Data Collection Method

In the primary data collection method, relevant information has been collected for the research. Related data to the objective of the study is collected using observation, interview and group discussion.

3.3.2.1 Observation

Observation is an important tool for primary data collection and it’s a method that directly involves the researcher. Observation only involves systematically watching and recording events, while being unbiased and without influencing or manipulating the events. During the observation of the maintenance facility, the researcher focused on basic points such as the facility layout, facility infrastructure, space availability and utilization, equipment placement and supporting facilities.

3.3.2.2 Interview

Interview is another tool for primary data collection. Related to this research, interview questions have been prepared for the maintenance personnel and the management, this is done to grasp the impact of the current layout from different perspectives. The main points raised in the interview are the current layout of the maintenance facility, workflow of the maintenance facility, areas of improvement from the perspective of both the maintenance personnel and the management, constraints and challenges of the current layout, the positive impacts and benefits of the current layout, future changes and flexibility, and maintenance frequency of agricultural machineries.

3.3.2.3 Group Discussion

Another method used for data collection to be used in the analysis part of the study is group discussion involving the technicians and the management. The aim of the group discussion is to identify and decide on the input elements needed for the CORELAP layout construction model. The input elements are the number of departments, the area of each department, activity relationship diagram and weights for the activity relationship. The group discussion helps in collaborating and brainstorming, knowledge sharing and consideration of multiple factors in deciding the area for each department, and especially the workshop/maintenance area.

3.3.3 Secondary Data Collection Method

In addition to primary data collection methods, another source of data for the study, secondary data collection methods have been utilized. The type of secondary data sources explored are job order register, literature review of related topics, studies done in the workshop, and other sources like the CNHI's (manufacturer of CASE IH agricultural machineries) dealer portal. The data gathered from these sources is helpful in understanding the requirements of a maintenance facility, material and equipment flow, and standard maintenance times for different maintenance operations and to understand future trends and technological advancements of the agricultural machineries and their maintenance facilities.

3.3.3.1 Literature Review

Overall, the literature review provides an overall overview of the facility layout planning, addressing its challenges, methods and applications. And it serves as a valuable resource for future researches and decision makers to further understand the facility layout problem and explore improvements in its practice. When it comes to studies and literature reviews done on the topic area, data and information about facility layout construction and improvement models, different requirements of a maintenance facility layout, layout optimization techniques, simulation tools and models and future trends and advancements in technology have been analyzed.

For this research, a total of 41 articles have been reviewed based on the relation and objective of the research. And accordingly, amendments to the data analysis approach has been done based on the literature gaps and to achieve an optimum facility layout plan.

3.3.3.2 Workshop Reports

To keep track of job orders, the maintenance activities and maintenance history of the machine, a work order register is used. The work register contains a record or list of various details, including work order number, job order date, machinery plate number, machinery manufacturer, machinery model, serial number, brief description of the repair, and related maintenance and spare parts cost. For the purpose of this paper, work registers of the year 2021, 2022 and 2023 have been used for collection relevant data of the maintenance process.

Using the work order register to collect data provides several benefits for facility layout modeling. As the register provides information about the agricultural machineries that have been serviced in and out of the workshop, it gives a relevant data for understanding the maintenance needs, maintenance frequency, equipment requirements, optimizing workflow, and plan for spare part inventory. Having this vital information helps during layout development of the facility for making informed decision about equipment placement, workflow optimization, safety considerations, and other necessary layout development requirements.

3.4 Methodology Framework

The methodology framework includes all key components of the research to ensure that the research is conducted in a rigorous and systematic manner, allowing for reliable and valid findings. The framework of this study encompasses a systematic approach to investigate, develop, optimize and validate layout of an agricultural machinery maintenance facility layout.

Methodological Framework

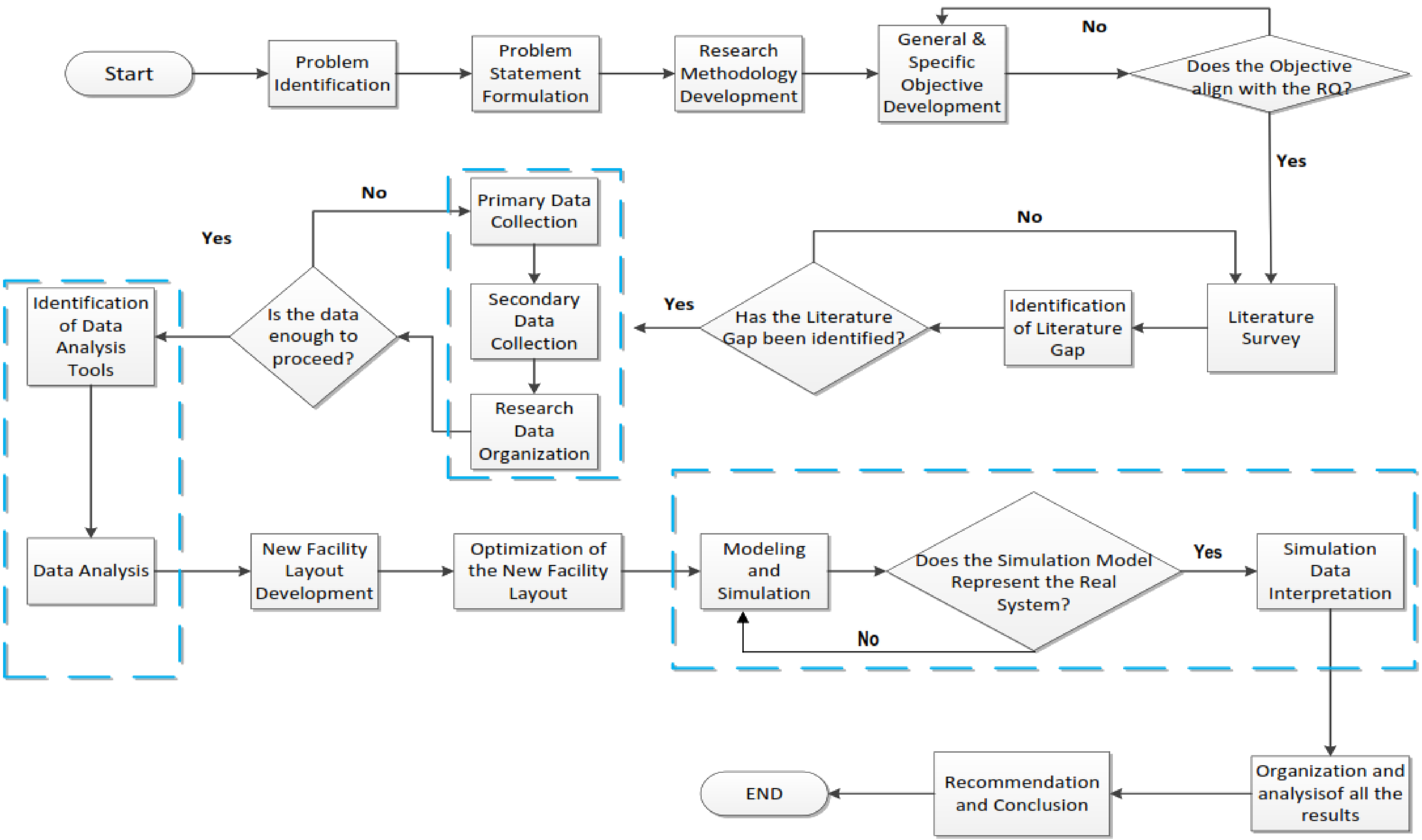


Figure 4: Methodology Framework

3.5 Data Analysis

In the previous sections the researcher uses different data collection methods to collect and analyze various data points to gain insights into maintenance activities, identify trends and make informed decisions. The collected data is then organized and data analysis is conducted. Data analysis is useful and plays a crucial role in evaluating and optimizing maintenance operations within an agricultural machinery maintenance facility.

For this research, data from primary and secondary data collection methods have been used. Data analyzed from primary data collection method mainly focused on the impact, workflow, workshop effectiveness and infrastructures of the existing facility layout. And secondary data collected mainly focuses on the types of maintenance, frequency of maintenance, facility infrastructure requirements and current/future maintenance facility trends and advancements.

The relevant data from the data collection methods has been analyzed to determine and evaluate different layout construction methods of the agricultural machinery maintenance facility, which will help in the placement of the departments.

The data from both is used to analyze the number and area of the departments in the maintenance facility. Also, the data is used to create activity relationship chart (ARC) between the different departments of the facility. And based on ARC, a layout is developed for the maintenance facility. In order to have an optimum layout arrangement of the departments, the newly developed facility layout will be further optimized using heuristic layout improvement model.

For the modeling and simulation of the agricultural machinery maintenance facility, discrete event simulation will be used. The key performance indicators for the simulation modeling are throughput and process time.

Lastly, the new and optimized agricultural machinery facility layout is compared to the existing layout to show and validate the proposed layout, and provide recommendation and conclusion.

3.6 Methodology Summary

Table 3: Methodology Summary

No.	Research Questions	Specific Objective	Data Collection Tools	Data Analysis Method
1.	How does the current layout of agricultural machinery maintenance facility impact the workflow and efficiency of maintenance operations?	To evaluate the impact of the current layout on the workflow and efficiency of maintenance operations in an agricultural machinery maintenance facility.	Primary Data Source Secondary Data Source	Physical observation of the facility & interview with maintenance and management staff
2.	What layout optimization techniques, configurations and operational strategies can be explored to optimize the utilization of space, resources, and workflow in the agricultural machinery maintenance facility?	To identify and evaluate layout optimization techniques, configurations and operational strategies considering factors such as travel distance, interdepartmental relationship, flow matrix and material handling cost.	Secondary Data Source **i.** Literature Review **ii.** Analyzed Data (work order register)	**1.** Facility layout development (CORELAP) **2.** Heuristic Optimization technique. (CRAFT)
3.	How can discrete event simulation modeling be effectively applied to model and analyze the layout of an agricultural machinery maintenance facility?	To assess the effectiveness of discrete event simulation modelling of the facility layout in representing and analyzing by comparing simulation results with real-world data and observation.	Secondary Data Source **i.** Literature Review **ii.** Analyzed Data (work order register)	Arena Simulation Modeling Software.

Chapter Four

4. Data Collection, Analysis, Results and Discussion

4.1 Introduction

In this section, data collected through primary and secondary data sources are presented. In the primary data collection method, observation, interview and workshop reports are used to collect data related to the objective of the study. Data from secondary data sources like, literatures, studies done in the workshop other data sources will be presented and analyzed.

4.2 Result of Data Collection

Results from the different data collection methods have been presented and the data collection is from observation, interviews, a review of workshop reports, literatures and other data collection sources. The data collection process has been conducted by the researcher.

Observation is an important tool for primary data collection and it's a method that directly involves the researcher. Observation can be done with the researcher being physically available at the observation site and also can be used as a secondary data collection method, as indirect, with the researcher relying on different means of capturing the event. Observation only involves systematically watching and recording events, while being unbiased and without influencing or manipulating the events.

Interview is another tool for primary data collection. Related to this research, interview questions have been prepared for the maintenance personnel and the management, this is done to grasp the impact of the current layout from the different perspective. The main points raised in the interview are the current layout of the maintenance facility, workflow of the maintenance facility, areas of improvement from the perspective of both the maintenance personnel and the management, constraints and challenges of the current layout, the positive impacts and benefits of the current layout, future changes and flexibility, and maintenance frequency of agricultural machineries. Other primary data collection methods used for data collection are workshop records, job requests and related information with the research objective.

In addition to primary data collection methods, another source of data for the study, secondary data collection methods have been utilized. The type of secondary data sources explored are literature review of related topics, studies done in the workshop, quarterly and yearly reports, and other sources like the internet and CNHI's dealer portal. The data gathered from these sources will help in understanding the requirements of a maintenance facility, material and equipment flow, and standard maintenance times for different maintenance operations and to understand future trends and technological advancements of the agricultural machineries and their maintenance facilities.

For the primary data collection, first the observation of the maintenance facility layout has been divided into sub sections to focus on the different parts of the facility. The observation results are described in the sub sections in three parts.

A. Workshop Environment

An agricultural machinery maintenance facility requires several key infrastructures and supporting facilities to effectively perform maintenance and other operations. Looking at Wereta International Business Plc.'s agricultural machinery maintenance facility, it has a traditional type facility layout having some of the basic maintenance infrastructures and supporting facilities. The facility has infrastructures and supporting facilities such as different offices, workshop space, employee facilities (café, changing room, showers), storage rooms (tire storage), machinery loading/unloading dock and machinery parking area.

The maintenance facility has main objectives of maintenance and pre-delivery inspection of agricultural machineries. The facility typically houses various types of machineries ranging from different model tractors and combine harvesters to agricultural implements. The facility (especially during peak farming season) bustling with maintenance technicians and supporting staff engaged in a range of tasks such as equipment inspection, repair, preventive maintenance and PDI operations.

Within the facility, there are different departments to address various aspects of the maintenance and inspection operation. Administration department deals with management and the overall functioning of the facility with the main task of budgeting, resource allocation and coordination between the different departments of the facility. Another department working under the administration is the operations department, dealing with the day-to-day operation of the facility like equipment deployment, task scheduling and monitoring and control of operations. The mechanical department mainly focuses on tasks like the repair and maintenance of mechanical parts and components of the machinery such as engine inspection and repair, overall servicing and general mechanical troubleshooting of the machinery. Electrical and electronics department, as the name indicates mainly focuses on the inspection, maintenance and repair of electrical components and systems of the agricultural machinery. The other department, welding and fabrication, has a main task of metal work and improvised modifications for agricultural machineries. This department is not organized well and often relies on outsourcing for different tasks. The safety department is another department operating in the facility and has a main focus of keeping safety regulation and creating a safe working environment in the facility. The final department is the PDI and implement assembly department, and this department has no designated staff as the technicians and supporting staff involved in this task are from the other departments and this operation is done in a way that will not affect and interrupt the other main operations of the facility.

B. Interdepartmental Relationship

The different departments in the facility have a work relationship for the smooth operation and work flow in the facility. As the administration department controls the overall operations of the maintenance facility, it has a close relationship with all the departments of the facility (especially with operations department) and this helps in providing resources, allocating budget and giving coordination support. The other department that has a close relationship with most of the departments related to activities of the facility is operations department/ this department especially works closely with administration and maintenance departments. As it is concerned with day-to-day operation functionality of the facility, it relies on the input and operations going on in the maintenance facility and this will help for allocating equipment's, scheduling tasks and monitoring of the operations. In addition to administration and operational department, PDI & implement assembly and metal & fabrication departments closely work with maintenance department. Specifically, the PDI & implement department has no designated staff, coordination with both maintenance and operations department is needed for scheduling and resource allocation. The safety departments also work closely with the departments in the facility to make sure that all the safety regulations have been met and that there is a safe working environment for the different operations and maintenance staff.

Overall, the agricultural machinery maintenance has a collaborative environment where different departments and expertise come together for the facilities operation. The facility has some basic infrastructures for the operations conducted in the facility. It's easy to see that the facility has plenty of areas that need improvement and development but with future development and improvement the facility will have the ability to attain the mission of the company and also enhance the level of quality and customer satisfaction.

C. Physical Observation

Observation has been used as a tool for collecting primary data related to the agricultural machinery maintenance facility. During the observation of the maintenance facility, the researcher focused on basic points such as the facility layout, facility infrastructure, space availability and utilization, equipment placement and supporting facilities.

During the observation the first thing that can be noticed about the maintenance facility is, that it was not designed with any of the layout construction methods and that it is a traditional type facility, like many others in Ethiopia. The maintenance area was not divided into designated spaces for a respective maintenance task, making it confusing and creating congestion in the maintenance process. The absence of a clear pathway in the maintenance area and between different work stations. This absence of a pathway in the maintenance facility can hinder maintenance personnel to move freely in the workshop and also moving in areas that are used for different tasks can lead to different injuries.

Maintenance facility infrastructures like training facility, spare part storage, metal shop, machinery washing and cleaning facility that can aid in the performance, smooth flow of work and customer satisfaction are not available. The facility has an objective of agricultural machinery maintenance and pre-delivery inspection (PDI), but the space availability is not compatible with the amount of service requests and PDI operations the facility can handle. Also, looking at the facility infrastructures that are available, changing room, breakrooms for customers and employees and parking area for newly arriving machineries and PDI operation areas need to be improved to achieve the mission of WIB to have a state-of-the-art maintenance facility.

Some positive observation of the maintenance facility is that the facility is well lit and well ventilated, as it has an open arrangement. The office being near the workshop may create an uncomfortable working condition but makes it ideal for monitoring and controlling the maintenance processes and operations.

Overall, the observations suggest that the current facility layout was not generally well designed and there is a potential room for improvement to enhance the effectiveness of the facility by addressing the different challenges. And the physical observation of the agricultural machinery maintenance facility provides a viral insight for improving the layout and also the different maintenance processes within the facility for better and improved efficiency of the facility.

The other source of information and method used for data gathering is an interview with the staff of the maintenance facility. For this research, an interview was conducted to for data collection and also to capture the input of the workshop management and maintenance personnel on the current layout design and configuration of the maintenance facility. A total of 8 participants have been selected for the interview. 6 maintenance personnel have been selected from different departments with mechanical, electrical and other skills and this is done to understand the impact of the facility layout with respect to the different maintenance processes available in the workshop. Also, 2 participants have been chosen from the management to have an insight into the impact of the facility layout related to monitoring and controlling the different procedures and operations of the facility. The interview questions for the maintenance personnel mainly focused on the challenges of the current facility layout and also the positive attributes of the layout. The questions for the interview are given in Annex 5 and Annex 6.

From the interviews conducted, it can be observed that, congestion in the maintenance and PDI operation is common and that it makes it hard for the maintenance personnel to move around easily and freely to perform their tasks. According to the participants, this congestion can be directly related to the lack of sufficient space availability, mismatch between the workshop performance capacity with the amount of task it handles and failure when designing the maintenance facility initially.

Another issue raised related to the current workshop layout during the interview is accessibility of spare parts. Spare parts storage in not available in the workshop, spare parts are stored about 300 m away from the workshop in a spare parts sale's office. And this long-distance travel and bureau procedure in retrieving spare parts leads to increased maintenance time and delay in the maintenance process. Related to storage areas in a workshop, one storage facility that is mandatory for a maintenance facility is tools storage or tools room. This is where maintenance personnel get the different mechanical, electrical, body work and power tools needed to perform their tasks with ease. In the case of WIB, a designated tools room is not available and maintenance personnel are given their own tool box that they carry around for basic maintenance and PDI operations. The participants point that the tool box weight about 60 kg and carrying that around for maintenance tasks will create delay in the maintenance process, prolongs the maintenance time and also leading to discomfort and increased risk of ergonomic injuries.

Looking at many advanced and modern maintenance facilities, they have a designated and dedicated area for a specific maintenance type and having these areas will help in placing equipment's and collaboration between different maintenance departments. One point all participants share related to the best practices and benchmarks of agricultural machinery maintenance facilities, WIB's workshop is far behind and being flexible and versatile according to the current technological trend and advancement is key for the success of the company and satisfaction of customers.

To get the input from management, 2 participants were selected. In addition to the above-mentioned points the points raised for the impacts of the current layout are limited visibility of the operations, lack of coordination between tasks and departments, inefficient workflow, control of workflow and processes, and safety of the maintenance personnel.

In summary, the interview conducted with the workshop staff shows that due to the different reasons mentioned, the performance of the workshop is not as effective as it should be or as close to the company mission. Thus, pointing out that these issues have to be dealt with to achieve the company mission and provide a state-of-the-art facility with an enhanced service quality for the satisfaction of customers.

Also, group discussion has been conducted to decide on some of the inputs for the CORELAP layout development technique. A total of 15 departments were identified for the maintenance facility (including main and supporting facilities) for the purpose of this study and according to the discussion and based on the experience and multiple factors considered, an area has been decided for each department. The findings of the group discussion are presented in the CORELAP analysis section.

As another source of data for the study, secondary data collection methods have been utilized. Analyzing supporting workshop documents, case studies done on the workshop performance, literature review on the topic area and other secondary data sources like CNHI's dealer portal have been used.

Different studies conducted on the research area have been reviewed to identify the various challenges and enhancements occurring in developing facility layout. Also, the various areas of unaddressed or shortcomings have been identified and a few have been used in this research to address those gaps. A total of 41 literatures, of which 16 are directly related to this research have been reviewed.

In addition to literature review, workshop reports have been analyzed for collecting viable data. To keep track of job orders, the maintenance activities and maintenance history of the machine, a work order register is used. The work register contains a record or list of various details, including work order number, job order date, machinery plate number, machinery manufacturer, machinery model, serial number, brief description of the repair, and related maintenance and spare parts cost. For the purpose of this paper, work registers of the year 2021, 2022 and 2023 have been used for collection relevant data of the maintenance process.

Table 4: Work Order Register Sample

		WERETA INTERNATIONAL BUSINESS PLC											Document No. D/SD-012	
	Title:- Work Order Register						Issue No. 1						Page No. 1	
W.O.R NUMBER	DATE		EQUIPMENT					COST						TOTAL COSTS
	WORK ORDER		PLATE NUMBER	MAKE	MODEL	SERIAL NUMBER	BRIEF DESCRITION OF REPAIR	LABOUR	PARTS	MILEAGE	LUBRICANT	MATERIAL	OUTSIDE REPAIR	
	OPENED	CLOSED												
C-2006001	6/13/2020	19/05/2021	OR1023	case	PUMA210	ZCBH53196	EPL calibration	-	-	-	-	-	-	-
FR-2011001	11/11/2020			case	MAXXUM125	ZGBE07493		-	-	-	-	-	-	-
W-2012001	12/14/2020	20/03/2021	s12 et	case	MAXXUM125	ZLBE01010	Engine unusual sound at round the front/replace crank shaft, bearing and Cong rod	-	-	-	-	-	-	-
C-2012002	12/21/2020	12/22/2020	S12 ET	case	MAXXUM125	ZLBE00071	fuel system problem/replace fule line	-	-	-	-	-	-	-
C-2012003	12/18/2020	12/18/2020		case	MAXXUM125	ZLBE00071	service engine in 900hr	-	-	-	-	-	-	-
C-2012004	12/19/2020	12/19/2020		case	MAXXUM125	ZLBE01649	service engine in 1200hr	-	-	-	-	-	-	-
C-2012005	12/21/2020	12/21/2020		case	MAXXUM125	ZLBE20131	service engine in 900hr	-	-	-	-	-	-	-
C-2012006	12/22/2020	12/22/2020		case	MAXXUM125	ZLBE2411	service engine in 1500hr	-	-	-	-	-	-	-
C-2012007	12/23/2020	12/23/2020		case	MAXXUM125	ZLBE20053	service engine in 600hr	-	-	-	-	-	-	-
I-2012008	12/23/2020	12/23/2020		case	MAXXUM125	ZLBE00450	service engine in 300hr	-	-	-	-	-	-	-
W-2012009	12/26/2020	1/29/2021	OR2801	case	MAXXUM125	ZLBE01697	Hydraulic system problem /	-	-	-	-	-	-	-

Using the work order register to collect data can provide several benefits for facility layout modeling. As the register provides information about the agricultural machineries that have been serviced in and out of the workshop, it will give a relevant data for understanding the maintenance needs, maintenance frequency, equipment requirements, optimizing workflow, and plan for spare part inventory. Having this vital information will help and aid during layout development of the facility for making informed decision about equipment placement, workflow optimization, safety considerations, and other necessary layout development requirements.

The two main activities done in the maintenance facility are, basic maintenance operations including routine service and pre-delivery inspection of newly arriving agricultural machineries. In the maintenance operations, agricultural machinery service, major overhauls, body and metal work are done. The pre-delivery inspection mainly contains inspection of newly arriving agricultural machineries and farmalization trainings.

The tables below show the overall maintenance types and operations for the years 2021, 2022 and 2023, and provide a relevant data for understanding the different maintenance and pre-delivery operations that can be used for the development of a facility layout.

Table 5: Work Order Register 2021, 2022 & 2023

No.	Description	Agricultural Tractors					Combine Harvester	Agricultural Implement
		MAXXUM 140	**MAXXUM 125**	**FARMALL110JX**	**PUMA 210**	**PUMA 155**	**HRNY4088**	**Different Brand and Model**
1	Manufacturer	CASE IH	CASE IH	CASE IH	CASE IH	CASE IH	CASE IH	Abolo, Alpler, Marzia, Nardi,
2	Corrective Maintenance	**11**	**266**	**129**	**1**	**-**	**10**	**-**
	Routine Service	**4**	**120**	**31**	**-**	**1**	**11**	**-**
	Pre-delivery inspection	**6**	**235**	**54**	**-**	**1**	**10**	**-**
3	Farmalization Training	**3**	**6**	**6**	**-**	**-**	**4**	**-**
4	Implement Assembly	**-**	**-**	**-**	**-**	**-**	**-**	**108**
	Total Work Order for each Item	**24**	**627**	**220**	**1**	**3**	**35**	**108**
						Total Work Order for 2021, 2022 & 2023		**1,018**

As shown in the table above, different operations of the maintenance facility and the different model agricultural machineries and implements supplied by WIB are shown. The table also shows the type of maintenance, amount of maintenance for the different models, farmalization trainings, PDI operations and agricultural implement assembly.

For the past three years (2021, 2022 & 2023) the total work orders, excluding unprocessed and other non-related job orders were well above 1018. But the major orders regarding the maintenance, routine service, PDI operations, implement assembly and farmalization trainings of agricultural machineries are a total of 1018 job orders.

Along with other information, one thing that be seen and understood is that, when it comes to the frequency of maintenance and PDI of agricultural machineries, MAXXUM 125 is the machinery that dominates and secondly is the FARMALL110JX model. A few (35) cases were recorded for the combine harvester and this is due to the limited number of combine harvesters supplied by WIB. Also, small numbers of other models and agricultural implement assembly are recorded. Considering all these factors, maintenance and PDI frequency is useful when it comes to the design and development of a facility layout. Also, keeping in mind future technological and product advancements is essential in having an optimal facility layout.

4.3 Analysis of Existing Maintenance Facility Layout

The existing maintenance facility layout has 8 workstations, office area, maintenance area, break room, changing room, storage area, consumable storage, machinery parking area, machinery loading/unloading area and PDI area. Also 2 departments outside of the facility, spare parts storage and implement assembly workstation, are available.

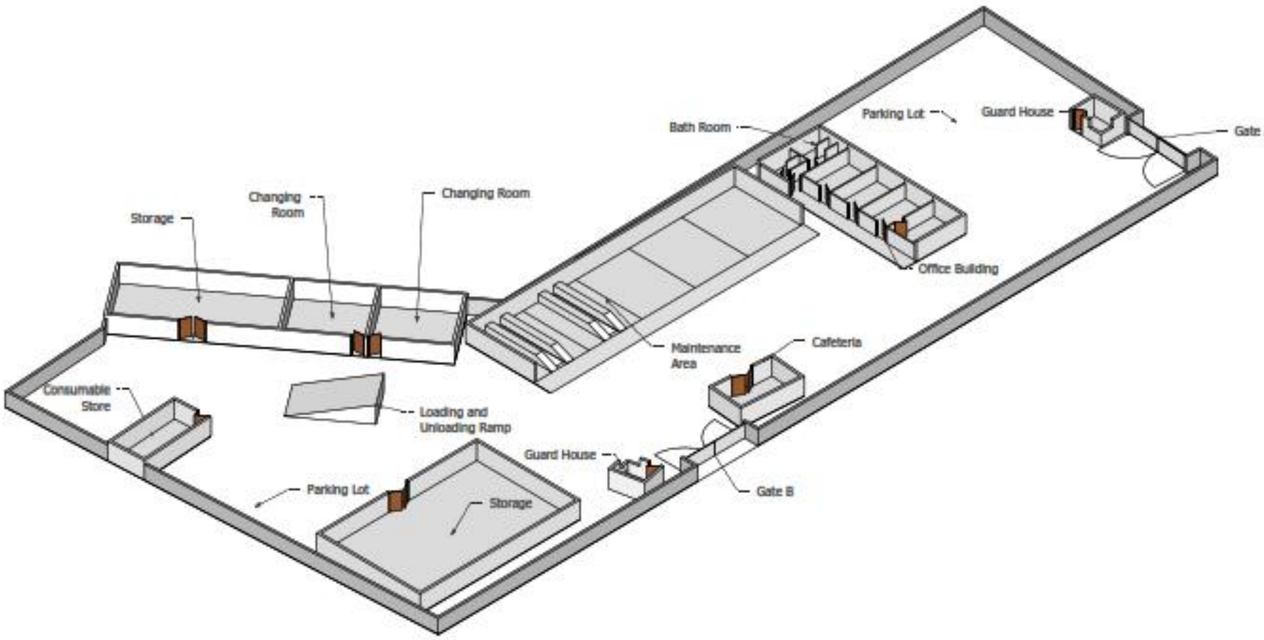


Figure 5: Existing Maintenance Facility Layout

Area of the different departments in the maintenance facility is shown in the table below. Also, as the departmental coding is necessary for allowing a clear communication and documentation within the maintenance facility, the departmental coding of the existing facility is as shown in the table below.

Table 6: Departmental Coding

No.	Letter Code for Department	Department Name	Area in m^2
1	MA	Maintenance Area	200
2	IA	Implement Assembly Area	600
3	MP	Machinery Parking Area	480
4	BR	Break Room (Café) and Training Facility (Lecture).	30
5	CR	Employee Changing Room	50
6	OB	Office Building	180
7	CS	Consumables Storage	50
8	SS	Spare Parts Storage	260
9	ML/U	Machinery Loading/Unloading Area	40
10	PDI	Pre-delivery Inspection	200

The monthly flow between the different departments of the maintenance facility are as shown in the table below.

Table 7: Inter-departmental Monthly Flow Matrix

From / To	MA	IA	MP	BR	CR	OB	CS	SS	ML/U	PDI
MA	-	3					4.63	12.36	16.22	3
IA	3	-				0.52				
MP			-			0.41			24.72	8.5
BR				-		0.52				
CR					-					
OB		0.52	0.41	0.52		-				
CS	4.63						-			0.44
SS	12.36							-		
ML/U	16.22		24.72						-	
PDI	3		8.5				0.44			-

4.3.1 CRAFT Application on the Existing Layout (Excel Add-In)

CRAFT uses flow data, distance-based costs incurred when transporting materials and adjacency relationships to improve a facility layout. To do that, CRAFT layout improvement algorithm requires different inputs to improve and generate a facility layout. The first requirements are the number of departments, the number of fixed points and the distance measure unit.

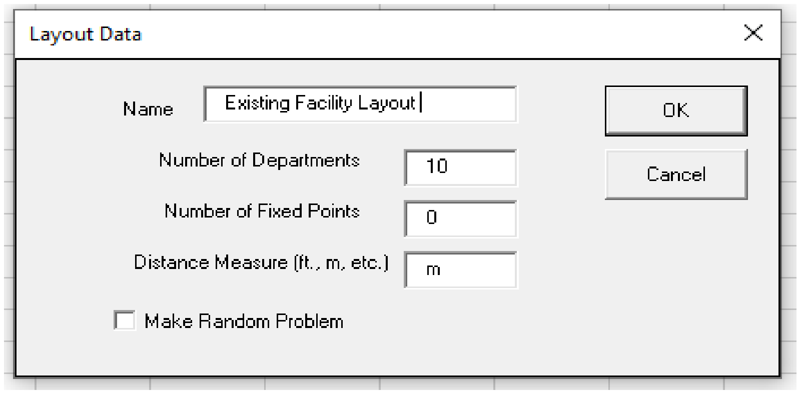


Figure 6: Layout Data Entering Modal Window

After the number of departments, number of fixed points and the distance measuring unit has been filled, pressing okay will open a new sheet, where the scale, length, width and area of the layout will be filled. The facility has been scaled down and after finding the centroids of the departments, multiplying the centroids with the scale value will give the up to scale value.

Facility Information

Scale-m/unit	1	Cells
Length-m	55	55
Width-m	40	40
Area-sq.m	2200	2200

Figure 7: Facility Information

After filling the scale, width and length of the facility, the next step will be to enter the department information and this includes the area of the departments and the system will automatically assign the number of cells needed for that area.

Department Information

	Name	F/V	Area	Cells
Dept. 1	D 1	V	200	200
Dept. 2	D 2	V	600	600
Dept. 3	D 3	V	480	480
Dept. 4	D 4	V	30	30
Dept. 5	D 5	V	50	50
Dept. 6	D 6	V	160	160
Dept. 7	D 7	V	50	50
Dept. 8	D 8	V	260	260
Dept. 9	D 9	V	40	40
Dept. 10	D 10	V	200	200

Figure 8: Department Information

The next data to be filled in the CRAFT layout improvement technique is the inter-departmental flow matrix between the departments.

Flow Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10
D 1	-	3					4.63	12.36	16.22	3
D 2	3	-				0.52				
D 3			-			0.41			24.72	8.5
D 4				-		0.52				
D 5					-					
D 6		0.52	0.41	0.52		-				
D 7	4.63						-			0.44
D 8	12.36							-		
D 9	16.22		24.72						-	
D 10	3		8.5				0.44			-

Figure 9: Flow Matrix

The transportation cost is the amount cost incurred for the handling and transport of goods and materials in the maintenance facility. The agricultural machinery maintenance facility utilizes a combination of manual material handling by senior and junior technicians and also mechanical assistance by a forklift. Materials required for the different maintenance tasks like tools, consumables, spare part and other necessary materials are manually handled by technicians to the different departments that require the materials in the facility. The forklift is mainly used in the implement assembly operation for loading & unloading of implements, transport of implements between the PDI, maintenance area and Implement assembly area and also to aid during the actual assembly operation of the implements.

Junior technicians have an average salary of 7500 and senior technicians have an average monthly salary of 24,407 birr. To find the amount of money earned per second:

Working days per month: **24 days**

Working hours per day: **8 hours**

$$\text{Working hours per month} = Working\ days\ per\ month\ \ X\ \ Working\ hours\ per\ day$$

$$= 24\ X\ 8 = \mathbf{192}\ \boldsymbol{hours} = \ \underline{\underline{\textbf{691,200 seconds per month}}}$$

And to find the amount of material handling per second:

$$= \frac{7{,}500\ Birr\ per\ month}{691{,}200\ seconds\ per\ month}$$

$$= \underline{\underline{\boldsymbol{0.01085069\ Birr\ per\ second}}}$$

To find the amount of the transportation cost per a given distance, material handling cost is divided with the average time taken to cover a distance in a second, which is 1.003 meter per second (Annex 8). And to find the transportation cost:

$$= \frac{0.01085069}{1.003}$$

$$= \underline{\underline{\boldsymbol{0.0108\ Birr\ per\ meter}}}$$

The transportation cost is found to be 0.0108 Birr per second for junior technicians. Using the same calculation, the transport cost for senior technicians is 0.0352 Birr per meter.

In some areas, specifically the implement assembly area, a UNI CARRIER forklift with 3.5 ton lifting capacity is used for the transport and assembly of different type agricultural implements.

To calculate the transport cost of the forklift, the purchase value, estimated salvage value, useful life, fuel cost per month, maintenance cost per month, operator cost and the total distance travelled in a month are required. The purchase price for forklift is 6,750,000 Birr and it’s estimated with expert opinion that the salvage value of the forklift is about 15% of the initial purchase value, which is 1,012,500 Birr. Assuming working hour of 8 hr/day, the average life span of a forklift is around 14,000 hours (about 5 years) and the monthly fuel and maintenance cost is 86,130 Birr and 15,000 Birr respectively. The forklift is operated by junior technicians with an average salary of 7,500 Birr and the average monthly travel distance of the forklift is 50,000 meters. Using the above inputs, the transportation cost of the forklift is calculated as:

Depreciation Cost

$$Depreciation\,\frac{Cost}{Year} = \frac{Purchase\ Price - Estimated\ Salvage\ Value}{Useful\ Life}$$

$$Depreciation\,\frac{Cost}{Year} = \frac{6{,}750{,}000 - 1{,}012{,}500}{5}$$

$$= \mathbf{1,147,500\,\frac{Birr}{Year}}$$

$$Depreciation\,\frac{Cost}{Month} = \mathbf{95,625\,\frac{Birr}{Month}}$$

Total Operating Cost per Month

$$Total\ Operating\,\frac{Cost}{Month} = (Fuel + Maintenance + Operator + Depreciation)Cost$$

$$Total\ Operating\,\frac{Cost}{Month} = 86{,}130 + 15{,}000 + 7{,}500 + 95{,}625$$

$$= \mathbf{204,255\,\frac{Birr}{Month}}$$

Operating Cost per Distance Travelled (in Meter)

$$Operating\,\frac{Cost}{Meter} = \frac{Total\ Operating\ Cost\ per\ Month}{Total\ Distance\ Travelled\ per\ Month}$$

$$Operating\,\frac{Cost}{Meter} = \frac{204{,}255\,\frac{Birr}{Month}}{50{,}000\,\frac{Meter}{Month}}$$

$$= \mathbf{4.085\,\frac{Birr}{Meter}}$$

The material handling cost of the forklift for the existing agricultural machinery maintenance facility layout is 4.085 Birr per meter of operation.

Now using the inter-departmental distance between departments, the material handling and transporting unit cost will be calculated for each department.

Cost Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10
D 1	-	3.78	0.216	0.108	0.108	0.075	0.324	3.24	0.27	0.054
D 2	3.78	-	3.888	3.618	3.834	3.963	3.456	6.804	3.51	3.672
D 3	0.216	3.888	-	0.367	0.432	0.14	0.54	2.916	0.54	0.302
D 4	0.108	3.618	0.367	-	0.162	0.216	0.27	3.294	0.216	0.054
D 5	0.108	3.834	0.432	0.162	-	0.291	0.108	3.348	0.054	0.108
D 6	0.075	3.963	0.14	0.216	0.291	-	3.996	3.132	0.345	0.054
D 7	0.324	3.456	0.54	0.27	0.108	3.996	-	3.564	0.054	0.108
D 8	3.24	6.804	2.916	3.294	3.348	3.132	3.564	-	3.499	3.24
D 9	0.27	3.51	0.54	0.216	0.054	0.345	0.054	3.499	-	0.162
D 10	0.054	3.672	0.302	0.054	0.108	0.054	0.108	3.24	0.162	-

Figure 10: Unit Cost Matrix of the Existing Layout

After entering all the above required inputs, the facility information, department information, flow matrix and cost matrix between departments the user will press the define facility option.

Layout Data

Problem Name:	Existing Layout
Number Depts.:	10
Fixed Points:	0
Dimension:	m

Define Facility

Figure 11: Layout Data Information

Which will then open a modal window selecting options, in this box the solution method and initial solution will be selected and to allow the user to define the initial layout, traditional craft and leave blank will be selected respectively. Also, the distance measure used will be rectilinear distance.

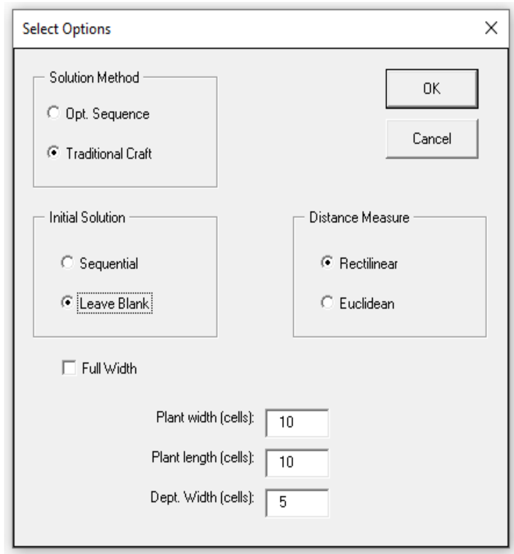


Figure 12: Select Option for the Existing Layout

After selecting the above options, the user will define the existing layout by filling the plant with the indices of the colors. After defining the layout using the corresponding color and pressing solve will give the initial cost of the layout and also gives department exchange suggestions based on the distance related cost, adjacency and department area. Following these procedures, the combined monthly material handling cost of the maintenance technicians and the forklift as analyzed by CRAFT program is a total monthly material handling cost of 611,434 Birr per month.

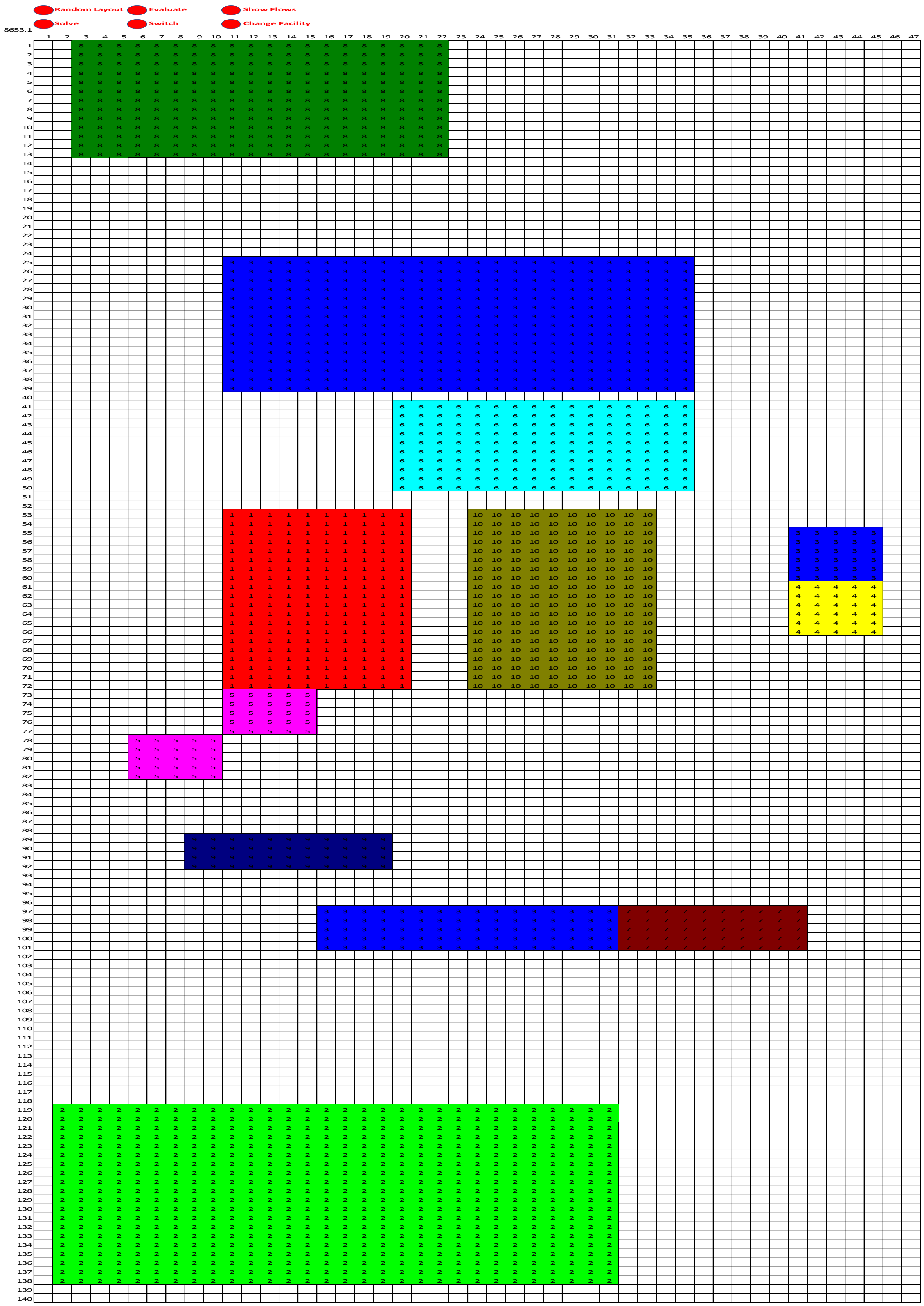


Figure 13: Existing Layout Placement and Cost

The travel distances between the different departments of the maintenance facility have been shown in the table below.

Table 8: Distance between workstations in meter

	1	2	3	4	5	6	7	8	9	10
1	-	350	20	10	10	7	20	300	25	5
2	350	-	360	335	355	367	320	630	325	340
3	20	360	-	34	40	13	50	270	50	28
4	10	335	34	-	15	20	25	305	20	5
5	10	355	40	15	-	27	10	310	5	10
6	7	367	13	20	27	-	37	290	32	5
7	30	320	50	25	10	37	-	330	5	10
8	300	630	270	305	310	290	330	-	324	300
9	25	325	50	20	5	32	5	324	-	15
10	5	340	28	5	10	5	10	300	15	-
					Total Travel between Departments				**6,364 m**	

4.3.2 Existing Facility Layout Simulation Modeling

In order to validate and show the improvements of the maintenance facility layout and also for detailed process modeling, visualization & animation and flow chart like interface Arena simulation software is used. The key performance indicators for the simulation modeling are throughput and process time.

The simulation will mainly include the departments that will directly affect the process time and throughput of the maintenance facility. The departments identified to directly affect the process time and throughput of the facility are maintenance department, PDI, implement assembly and machinery loading/unloading. But also, other departments and operations in the facility like, spare parts storage, consumables storage and training operation, both theoretical and practical trainings, are also represented in the simulation modeling of the existing facility layout.

The necessary time studies required for the different operations and processes of the simulation modeling have been recorded (Annex 8). Following this, every time study has been analyzed using Arena Input Analyzer to identify their probability distribution, visualizing data and distribution, and reporting and documentation. This is done to ensure the model to be build is based on accurate and representative input data and also to improve the accuracy and reliability of the simulation results. A sample of the maintenance time study analyzed in the input analyzer is shown in the figure below.

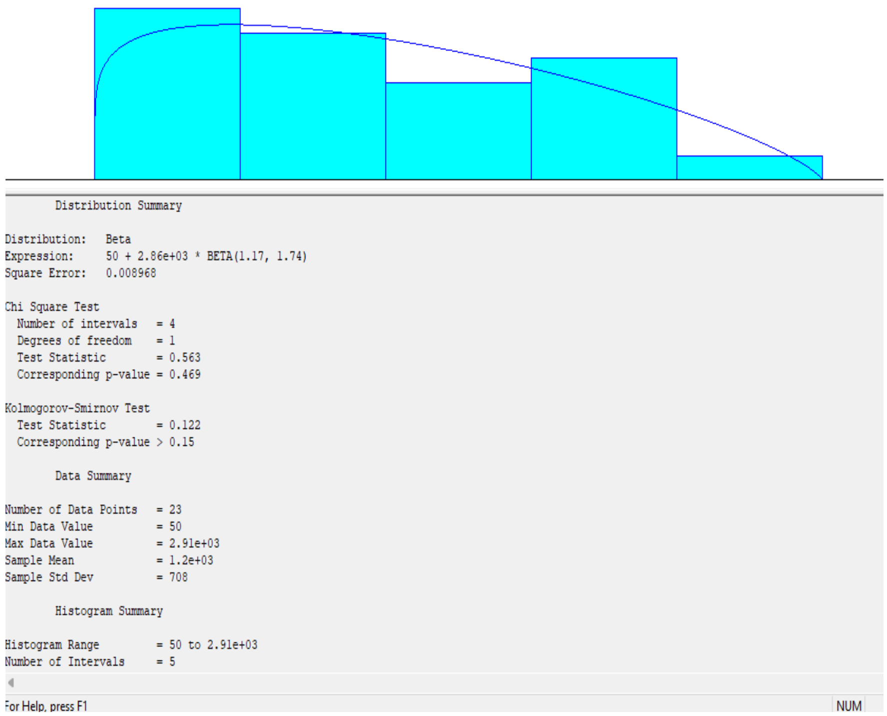


Figure 14: Output of Arena Input Analyzer

The result of the input analyzer results of distribution type and expression for the different maintenance department facilities selected has is shown in the table.

Table 9: Activities and their results of the input analyzer

Activity Description	Distribution Type	Expression
Maintenance service	Exponential	8.06e+03 + 91 * BETA(0.672, 0.626)
Pre-delivery inspection	Beta	364 + 50 * BETA(0.783, 0.522)

Implement assembly	Exponential	240 + EXPO(420)
Theoretical training	Beta	180 + 49 * BETA(0.616, 0.663)
Practical training	Poisson	POIS(90.6)
Loading/ Unloading	Lognormal	5.03 + LOGN(0.907, 0.883)
Machinery Parking	Weibull	6.23e+03 + WEIB(7.04e+03, 0.516)

The modeling process began by modeling and mapping of the maintenance facility workflow within the Arena simulation software. For this, different flow chart and data modules have been utilized. Resources that will be used in the simulation have been defined according to the existing facility layout and this includes 2 management staff, 15 technicians, 2 garage pits, 3 maintenance bays, spare parts, consumables and parking space for 25 machineries. Other departments like changing room, café and storage areas are not included in the simulation modeling as the departments don't directly contribute to the process time or throughput of the facility. Also, as the Arena simulation software used is a student version, the number of entities that can be simulated is limited to 150, therefore, for this simulation modeling process, 148 entities are used.

In order to find the number of replications needed for the simulation, the first 10 replication of the simulation and the results are used to identify the number of replications required to identify the key performance indicators, for this case, process time and throughput. Using the below results, the number of replications for the processes is calculated with a confidence rate of 95% and an acceptable error of 5%.

Table 10: Result of 10 replications for the simulation

Number of Replications	Process Time Output Results (min)
1	31,665.63
2	27,001.36
3	25,046.34
4	34,995.05
5	26,638.15
6	27,453.66

7	40,008.27
8	23,689.29
9	33,019.59
10	29,355.23
Mean	**29,987.26**
Standard Deviation	**4,975.94**

The number replication is calculated using the formula:

$$n = \left(\frac{Z_{\propto/2} \times \sigma}{E}\right)^2$$

Where, n: number of replications

$Z_{\propto/2}$: Z-value for the desired confidence

σ: Standard deviation

E: acceptable error margin

For process time:

$$E = 0.05 \times 29{,}987.26 = 1{,}499.36$$

$$n = \left(\frac{1.96 \times 4{,}975.94}{1{,}499.36}\right)^2$$

$$\boldsymbol{n \approx 42\ Replications}$$

The results show that a replication of 42 is needed for the process time, to achieve a confidence level of 95% with an acceptable error margin of 5%.

From the time study conducted for the different departments of the maintenance facility represented in the simulation modeling, the facility has a total process time of 31,168.92 min (519.48 hr) and a standard deviation of 6,347.14 min (105.79 hr). To find the range in which the real process time should fall in so as the simulation model accurately represents the real model with 95% confidence rate and 5% error margin is calculated using the data from the first 10 replications runs as:

$$CI = Simulated\ Mean\ \pm \left(Z \times \frac{Simulated\ Standard\ Deviation}{\sqrt{n}}\right)$$

$$CI = 29{,}987.26\ \pm \left(1.96\ \times \frac{4{,}975.94}{\sqrt{42}}\right)$$

$$CI = 29{,}987.26\ \ \pm 1{,}505.06$$

Lower Limit = $29{,}987.26\ \ - 1{,}505.06 = 28{,}482.20$

Upper Limit = $29{,}987.26\ \ + 1{,}505.06 = 31{,}492.32$

$$CI = [28{,}482.20, 31{,}492.32]$$

With a simulation replication number of 42 and a replication hour of 1,248, the total average process time generated by the simulation is 31,100.94. Therefore, as the real process time and simulated process time fall between the range [28,482.20, 31,492.32], the simulation model with 31,100.94 average process time is accurate to represent the real process of the maintenance facility.

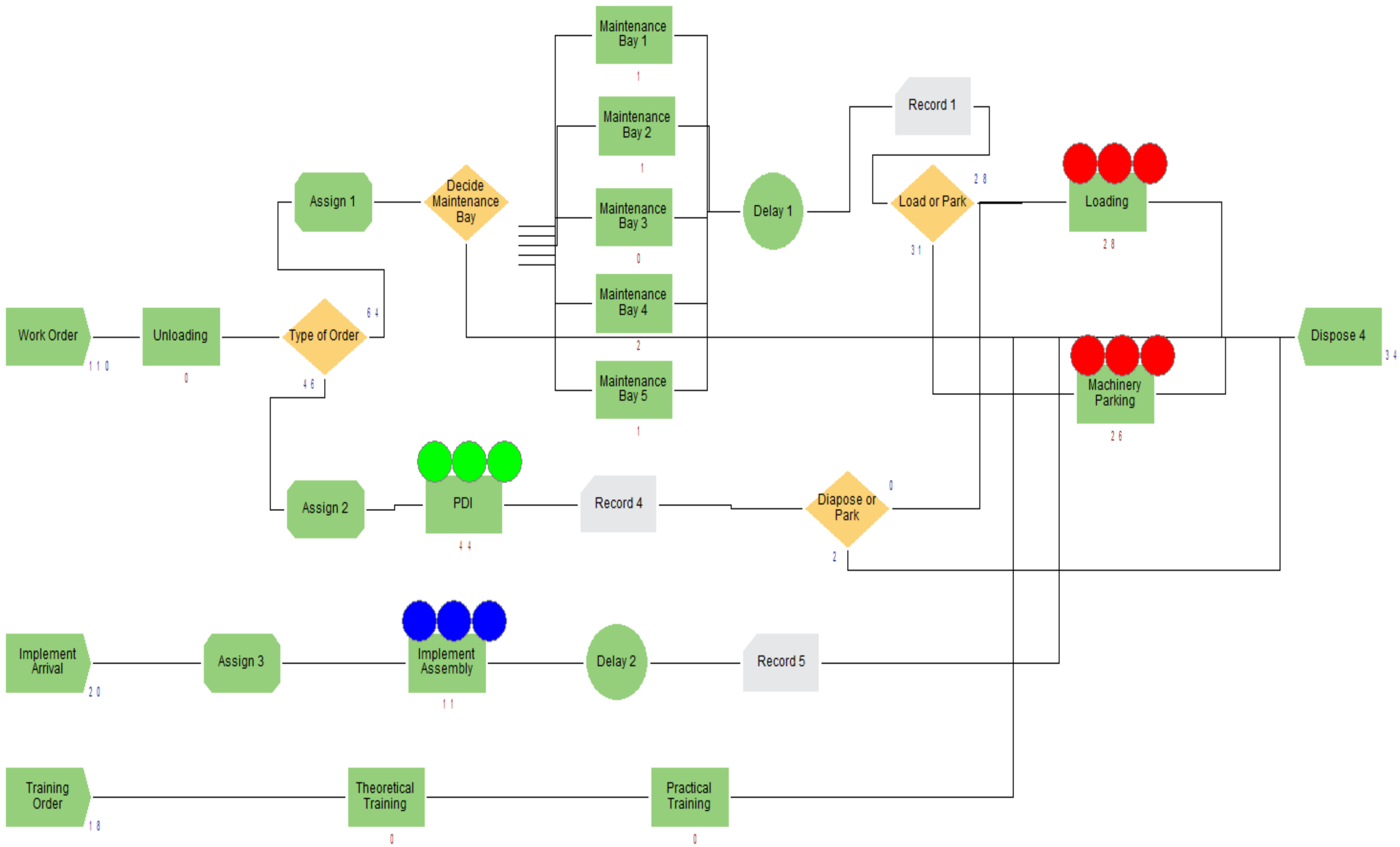


Figure 15: Existing Layout Simulation Model

With the input of 148 entities to the system, the result of the simulation model resulted in an average throughput of 40 units and this indicates the total number of tasks/units completed over the replication period of 1,235 hr. also, for the given replication period, the process time from the simulation, which is the average process time from the 42 replication runs is 31,100.94 min (518.35 hr.) and this process time indicated the total time it takes an entity from start to completion of the required operation. The other observation is that the simulation shows the existence of a bottleneck in the system particularly in the PDI, where out of the 46 entities that enter the department only 5 are processed and 41 are in queue. Also, for the loading department, there are 28 entities waiting to be processed, for implement assembly there are 11 units in process and for the maintenance there are 5 units in process. A queue is seen at the parking area, but as parking is a resource with 35 parking areas, the queue just shows the amount of machineries parked in the maintenance facility.

In summary, the existing facility layout simulation model mimics the real process of the maintenance facility with 95% confidence interval. And looking at the results of the simulation output report, there are critical areas that need improvements as these areas show congestion long queue time which will affect the performance of the facility layout.

4.4 CORELAP Facility Layout Construction

CORELAP (Computerized Relationship Layout Planning) is one of the layout construction techniques used for the development and optimization of the arrangement of various components within a facility. It is useful in determining the optimal placement of equipment's, workstations, departments and other resources leading to decreased handling cost and improved work efficiency (Boby & Bibin, 2018; Kasemset et al., 2023; Wibisono & Wilasto, 2023).

As a construction type layout development technique, CORELAP, requires an initial input in order to develop a layout. The initial inputs required are number of departments, area of each department, a relationship chart and weight for the relationship chart. The weights are given for the letter symbols to be used for the closeness relationship. The letters and their corresponding values or weight is given as, A – Absolutely Necessary, E – Especially Important, I – Important, O – Ordinary Closeness, U – Unimportant and X – Not Desirable

(Boby & Bibin, 2018; Kasemset et al., 2023; Potadar & Kadam, 2019). The input requirements are further discussed below.

A. Number of Departments

Including main facilities, supporting facilities and future expansion area, 15 departments have been identified for the agricultural machinery maintenance facility.

The departments identified are office building, maintenance area, break room (Café), changing room, general storage, machinery parking area, machinery loading/unloading area, tools and equipment room, spare part storage, training facility, implement assembly area, cleaning and washing area, metal and fabrication, consumables storage, first aid room (clinic), PDI and future expansion area.

Depending on the type of activity and also to introduce the idea of flexibility for minimizing space and using a single area for different operations, some departments serve different operations. The departments that are interchangeable are: break room & training facility (lecture room), PDI & training facility (practical) and parking area & implement assembly.

B. Department Area

Based on the group discussion conducted for identifying the area for each department in the maintenance facility, the departments identified and the area of each department is presented in the table below.

Table 11: Area and coding of departments

No.	Department	Area in m^2	Coding
1.	Office Building (Including managerial office, reception area, library, other offices, rest room and expansion area).	450 m^2	OB
2.	Maintenance Area (Including 4 garage pits, 5 service bay and expansion area).	600 m^2	MA
3.	Engine Shop (for rebuilding and engine detail work).	50 m^2	ES

4.	**Break Room (Café) and Training Facility (Lecture Room).**	50 m^2	BR
5.	Employee Changing Room (male and female changing rooms with shower and rest room).	100 m^2	CR
6.	General Storage (for storage of removed parts, reusable components, salvaged materials).	100 m^2	GS
7.	Machinery Parking Area (machinery arriving for PDI & machinery storage after PDI).	500 m^2	MP
8.	Machinery Loading/Unloading Area	50 m^2	ML/U
9.	Tools and Equipment Room (for storage of maintenance tools and specialty tools).	100 m^2	T&E
10.	Spare Parts Storage	150 m^2	SS
11.	**Implement Assembly Area/PDI/Training Facility (Practical Training)**	500 m^2	IA/PDI
12.	Cleaning and Washing Area	50 m^2	C&W
13.	Metal and Fabrication Shop	50 m^2	MS
14.	Consumables Storage	50 m^2	CS
15.	First Aid (Clinic) Room	50 m^2	FA

C. Relationship Chart

Closeness Rating

Based on the group discussion conducted, the closeness rating of each departments in the maintenance facility is presented below and the percentage of the relationship rating between the departments is as shown in the table below.

Table 12: Percentage of relationship rating

No.	Rating	No. rating available in the chart	Percentage
1	A – Absolutely Necessary	9	8.57 %
2	E – Especially Important	21	20 %

3	I – Important	8	7.62 %
4	O – Ordinary Closeness	16	15.25 %
5	U – Unimportant	49	46.66 %
6	X – Not Desirable	2	1.90 %
	Total	**105**	**100 %**

Relationship chart of the different departments in the agricultural machinery maintenance facility is as described below.

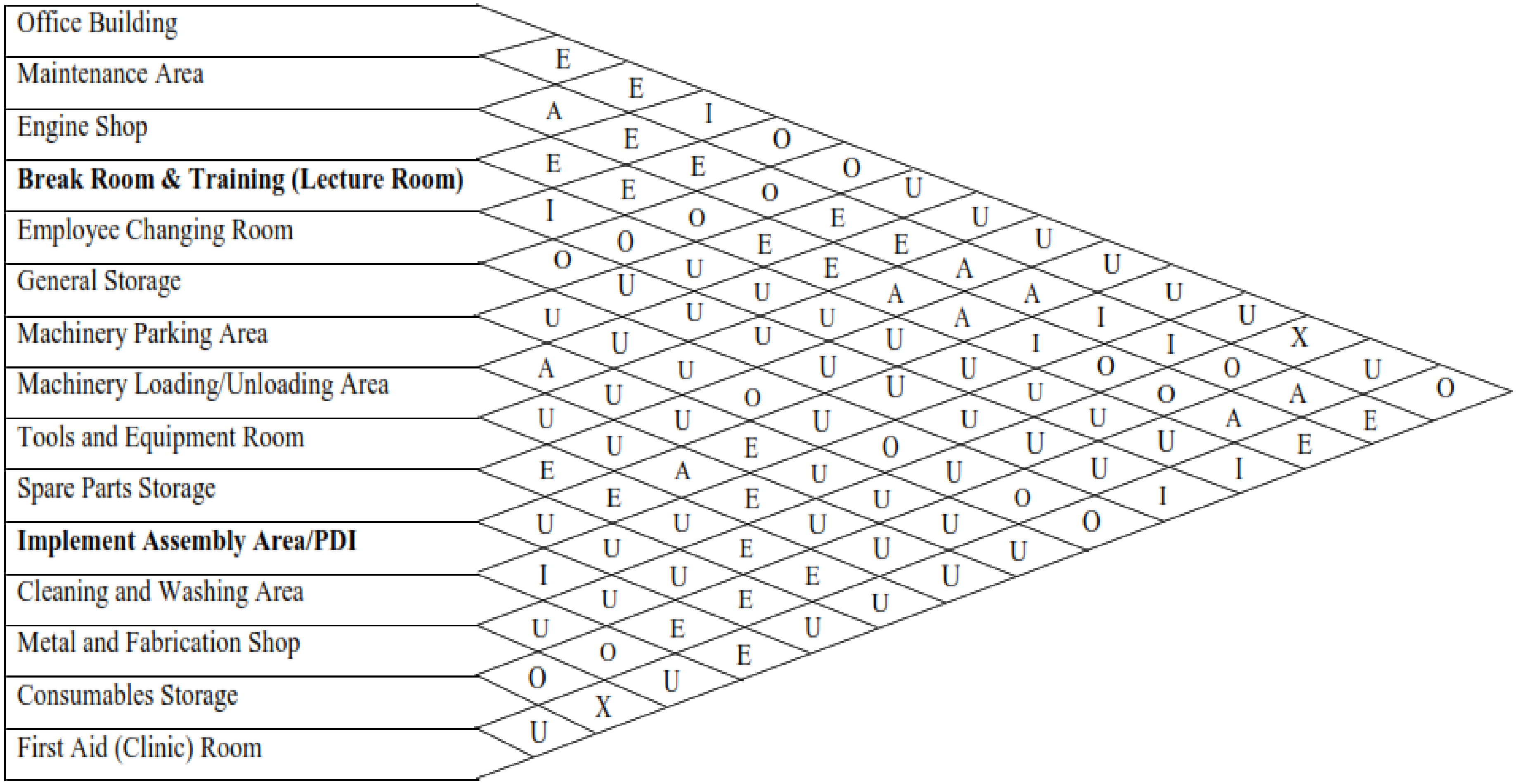


Figure 16: Relationship Chart

Table 13: Departmental Dimension and Number of Grids

No.	Department	Area in m^2	Number of Grids
1.	OB	450 m^2	9
2.	MA	600 m^2	12
3.	ES	50 m^2	1
4.	BR	50 m^2	1
5.	CR	100 m^2	2
6.	GS	100 m^2	2
7.	MP	500 m^2	10
8.	ML/U	100 m^2	2
9.	T&E	100 m^2	2
10.	SS	150 m^2	3
11.	IA/PDI	500 m^2	10
12.	C&W	50 m^2	1
13.	MS	50 m^2	1
14.	CS	50 m^2	1
15.	FA	50 m^2	1

D. Weight for Relationship Chart

The weight given for the relationship between the departments of the facility is given as: A – Absolutely Necessary (6), E – Especially Important (5), I – Important (4), O – Ordinary Closeness (3), U – Unimportant (2) and X – Not Desirable (1) (Boby & Bibin, 2018).

Total closeness rating for the departments is calculated using the formula:

$$TCR = \sum_{i=1, i \neq j}^{m} W_{ij}$$

The total closeness rating and placement sequence of the departments in the agricultural machinery maintenance facility have been shown in the table below.

Table 14: Total closeness rating

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	A 6	E 5	I 4	O 3	U 2	X 1	TCR	Placement
1	-	E	E	I	O	O	U	U	U	U	U	U	X	U	O	-	2	1	3	7	1	38	**12**
2	E	-	A	E	E	O	E	E	A	A	I	I	O	A	E	4	6	2	2	-	-	68	**1**
3	E	A	-	E	E	O	E	E	A	A	I	O	O	A	E	4	6	1	3	-	-	67	**2**
4	I	E	E	-	I	O	U	U	U	U	U	U	U	U	I	-	2	3	1	8	-	41	**10**
5	O	E	E	I	-	O	U	U	U	U	U	U	U	U	I	-	2	2	2	8	-	41	**11**
6	O	O	O	O	O	-	U	U	U	O	U	O	U	O	O	-	-	-	9	5	-	37	**14**
7	U	E	E	U	U	U	-	A	U	U	E	U	U	U	U	1	3	-	-	10	-	41	**7**
8	U	E	E	U	U	U	A	-	U	U	A	E	U	U	U	2	3	-	-	9	-	45	**6**
9	U	A	A	U	U	U	U	U	-	E	E	U	E	E	U	2	4	-	-	8	-	48	**3**
10	U	A	A	U	U	O	U	U	E	-	U	U	U	E	U	2	2	-	1	9	-	43	**4**
11	U	I	I	U	U	U	E	A	E	U	-	I	U	E	E	1	4	3	-	6	-	50	**8**
12	U	I	O	U	U	O	U	E	U	U	I	-	U	O	U	-	1	2	3	8	-	38	**13**
13	X	O	O	U	U	U	U	U	E	U	U	U	-	O	X	-	1	-	3	8	2	32	**15**
14	U	A	E	U	U	O	U	U	E	E	E	O	O	-	U	2	3	-	3	6	-	48	**5**
15	O	E	E	I	I	O	U	U	U	U	E	U	X	U	-	-	3	2	2	6	1	42	**9**

The department with the greatest TCR value will be selected to be placed first in the layout development and according to the above table the department with the highest TCR value is department 2, maintenance area. Then according to the sequence of placement from the above table, the order of placement of the departments in the agricultural machinery maintenance facility is: 2-3-10-14-8-7-11-15-4-5-1-12-6-13.

4.4.1 CORELAP Application

The input requirements of CORELAP have been identified and based on the relationship between departments and TCR, the sequence for the placement the departments have also been identified. The department placement procedures for CORELAP are (Boby & Bibin, 2018):

1. The first department placed in the layout is the one with the greatest TCR value. If there is a tie, then choose the one with more A’s (E’s, etc.).
2. The second department is the one with an A (or E, I, etc.) relationship with the first one. If a tie exists, choose the one with the greatest TCR value.
3. The next department is the one with an A (E, I, etc.) relationship with the already placed departments. If a tie exists, choose the one with the greatest TCR value.
4. Procedure continues until all departments have been placed.

The CORELAP application based on the results is conducted below.

Iteration – 1

Based on the TCR value of the departments, department 2 (maintenance area) has the highest TCR value of 68 and is the first department to be placed. Number of grids for department 2 is 12 and will be placed in the center.

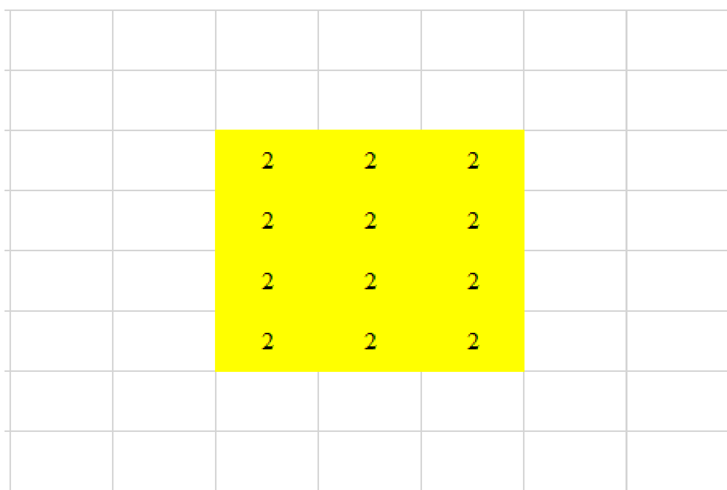


Figure 17: CORELAP Iteration 1

Iteration – 2

Determined by the closeness value with the first department, the second department to be placed is department 3(engine shop). As the PR value for department 3 would be the same in every position, it can be placed anywhere with adjacent to the existing department. Number of grids for department 3 is 1.

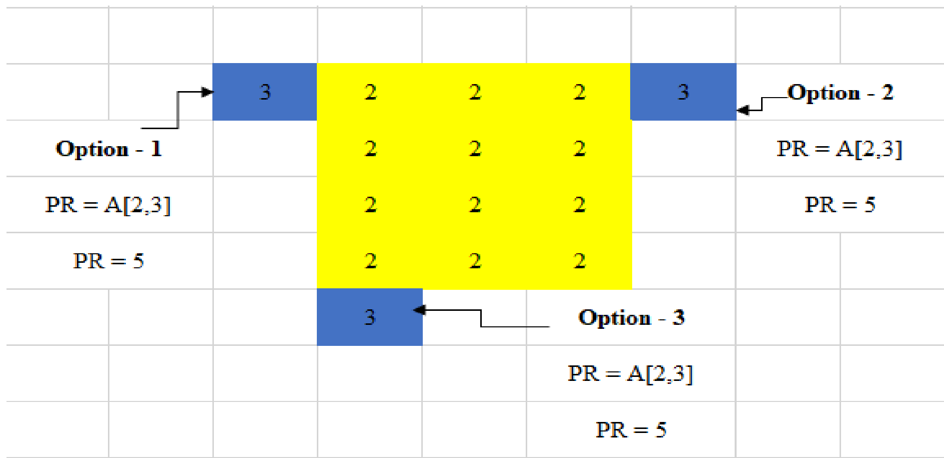


Figure 18: CORELAP Iteration 2

Iteration – 3

The third department to be placed is department 9 (tools & equipment), as it has an A relationshop with the previously placed two departments. The placement of department 9 is decided based the the highest PR value. Number of grids for department 9 is 2.

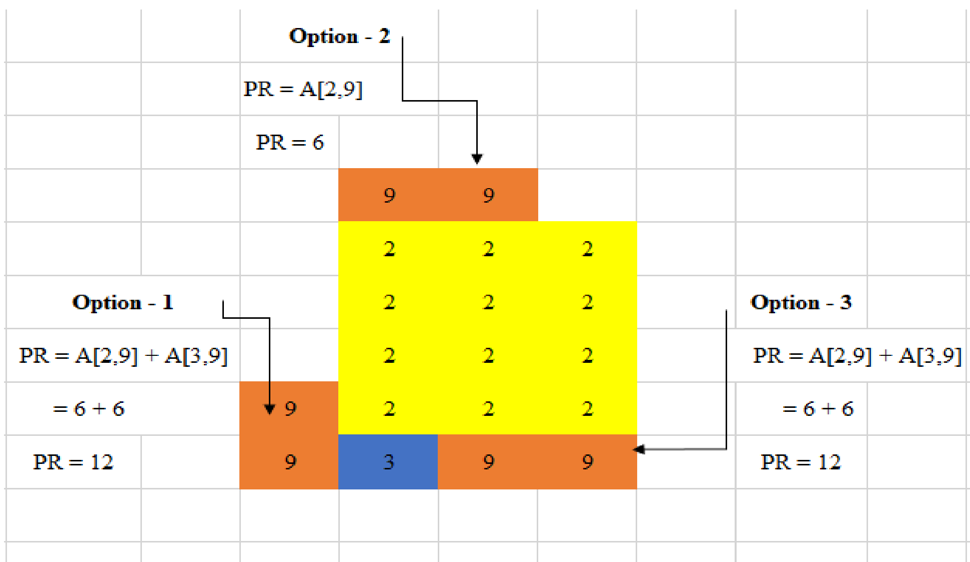


Figure 19: CORELAP Iteration 3

As it can be seen from the figure, there are three options to place department 9 and two of them, option 1 & 3 give an equal PR value, therefore department 9 can be placed in either of the two positions. For this case, option number 1 is selected.

Iteration – 4

The other department with a higher relationship with the preiously placed departments is department 10 (spare parts storage). Different options are tried to find the best space with the highest PR value. Number of grids for department 10 is 3.

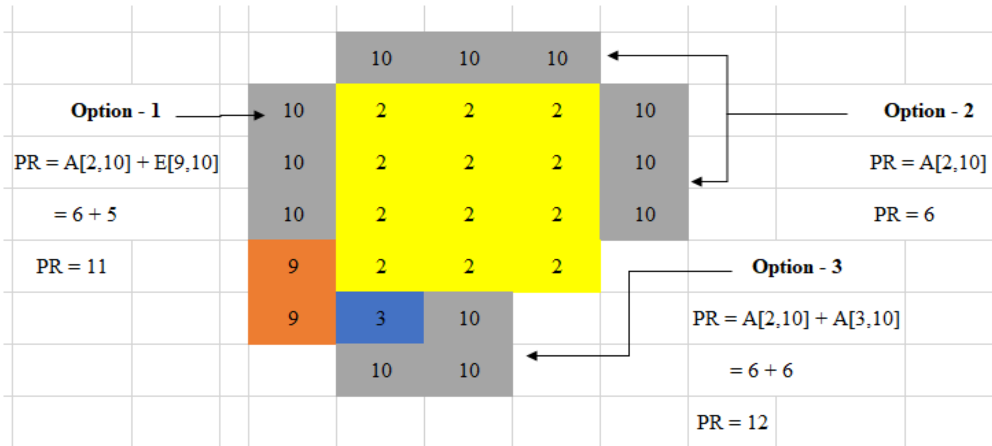


Figure 20: CORELAP Iteration 4

Based on the selected 3 options to place department 10, option 3 has the greatest PR value of 12 and therefore will be selected to for the position of department 10.

Iteration – 5

The fifth department to be placed and the one with a better relationship with the other departments is department 14 (consumables storage). Different positions will be evaluated and the one the highest PR value will be selected. Number of grids for department 14 is 1.

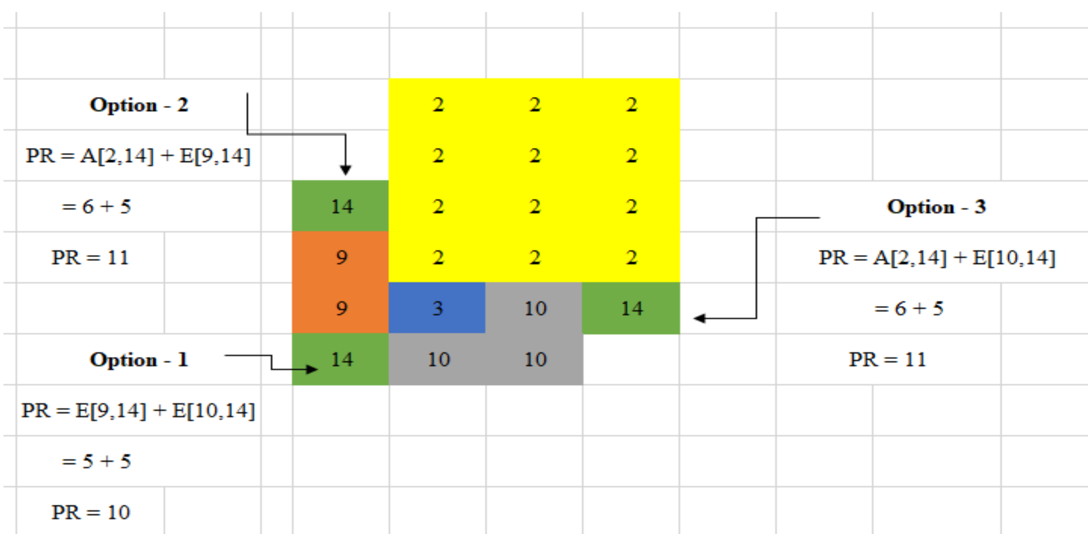


Figure 21: CORELAP Iteration 5

Three different positions, for the position of department 14 were selected and the one with the highest PR value are option 2 & 3. Either positions can be selected for the placement of department 14 and for this case option 3 has been selected.

Iteration – 6

The sixth department to be placed is department 8 (machinery loading/unloading). Out of the positions the one with the highest PR value will be selected for department 8. Number of grids for department 8 is 2.

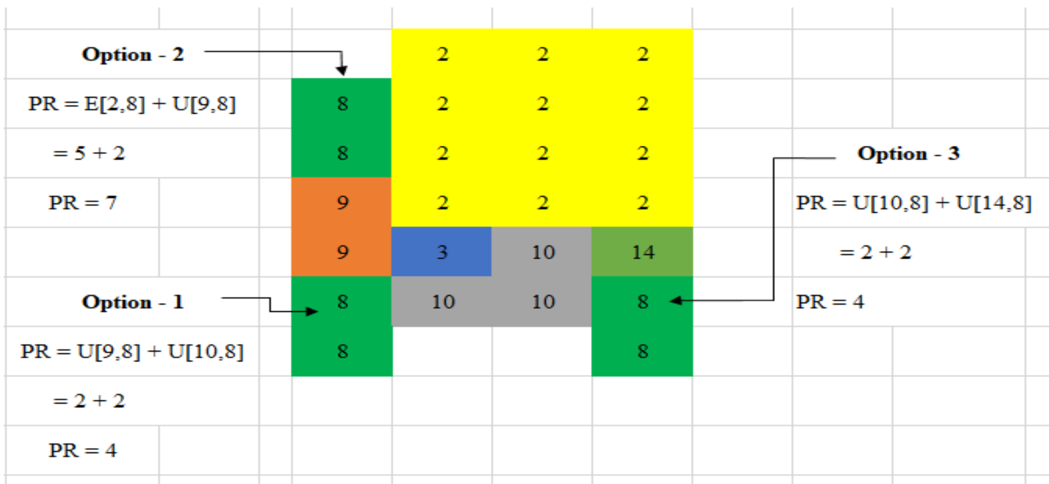


Figure 22: CORELAP Iteration 6

Iteration – 7

The seventh department to be placed in the layout is department 7 (machinery parking). The position with the highest PR value will be selected and numbers of grids for department 7 is 10.

Figure 23: CORELAP Iteration 7

Depending on the results of the relationship chart and closseness rating, three options were selected for the placement of department 7 and the one with the highest PR value is option 1 with a PR value of 12, thus it will be the desired position for the placement of the department.

Iteration – 8

The eighth department to be placed is department 11, and the department is one of the two departments that are flexible and can be used for different operations. The department can be used for implement assembly, PDI and training (practical training). Number of grids for the department is 10.

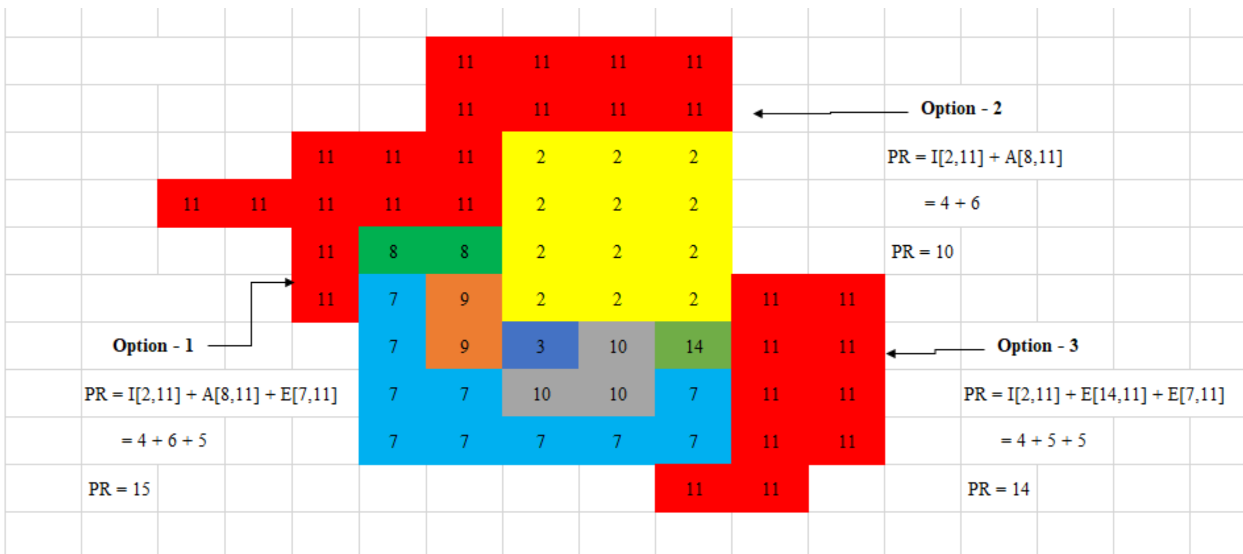


Figure 24: CORELAP Iteration 8

Out of the three options, the highest, with a PR value of 15 is option 1.therefore department 11 is placed in the position of option 1.

Iteration – 9

The ninth department to be placed is department 15 (first aid/clinic). As this department is used to treat on job injuries, relationship with the different departments and the requirement of the department has been taken into consideration. The number of grids for the department is 1.

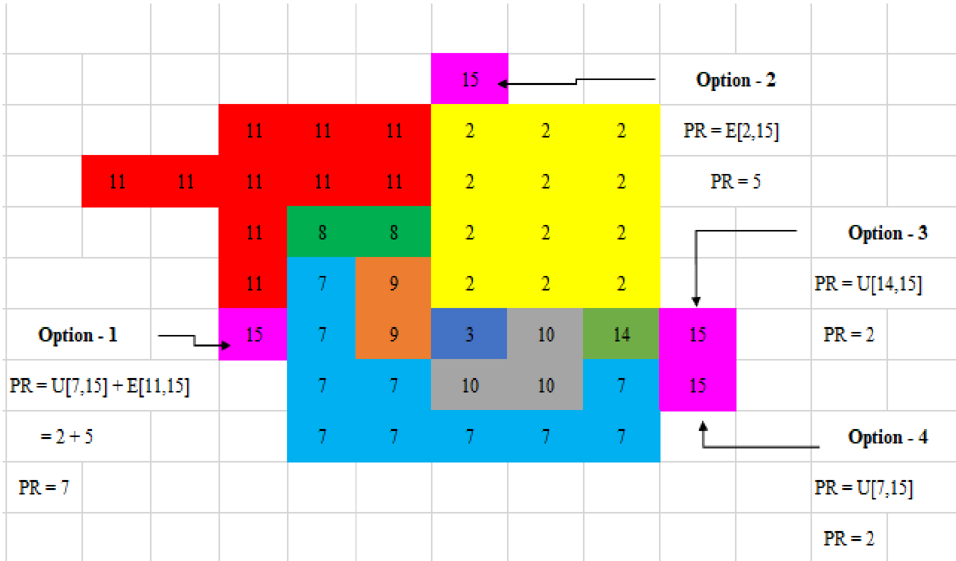


Figure 25: CORELAP Iteration 9

Four positions have been considered for the placement of the department and the one with the highest PR value out of the four is option 1 with a PR value of 7. Therefore position 1 will be the placement of department 15.

Iteration – 10

The tenth department to be placed in the agricultural machinery maintenance facility layout is department 4. This is the other department that has a flexible working environment. The department can be used as a break room (café) and also a meeting and training room (lecture room). Number of grids for the department is 1.

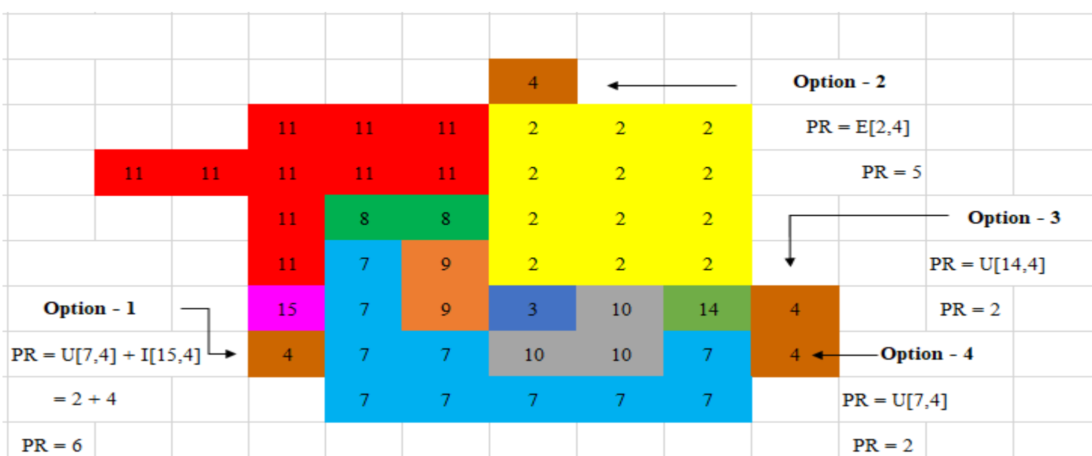


Figure 26: CORELAP Iteration 10

Four options have also been considered for the placement of department 4 and the option with the highest PR value of 6 is option 1. The department will be placed accordingly.

Iteration – 11

The eleventh department to be placed is department 5 (employee changing room). The position with the highest PR value will be selected for the position of the department. Number of grids for the department is 2.

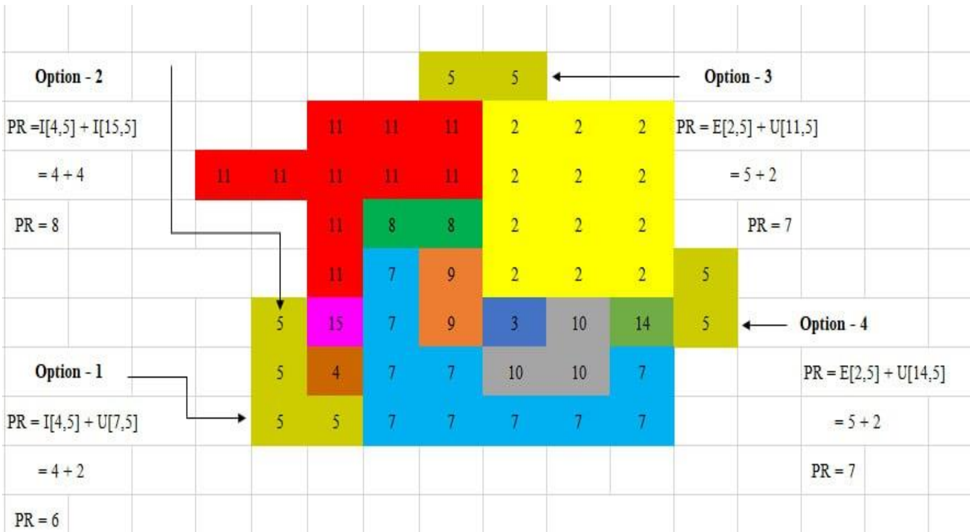


Figure 27: CORELAP Iteration 11

According to the activity relationship chart and the type of department were considered for the placement of the department. Four possible options were selected and the option with the highest PR value of 8 is option 1 and therefore the department will be placed there.

Iteration – 12

The twelfth department to be placed is department 1 (office building). The office building incorporates managerial office, reception area, digital library, rest room and other offices. The relationship with different departments and the type of work environment for the department were considered and appropriate conditions are taken for the position of the department. Number of grids for the department is 9.

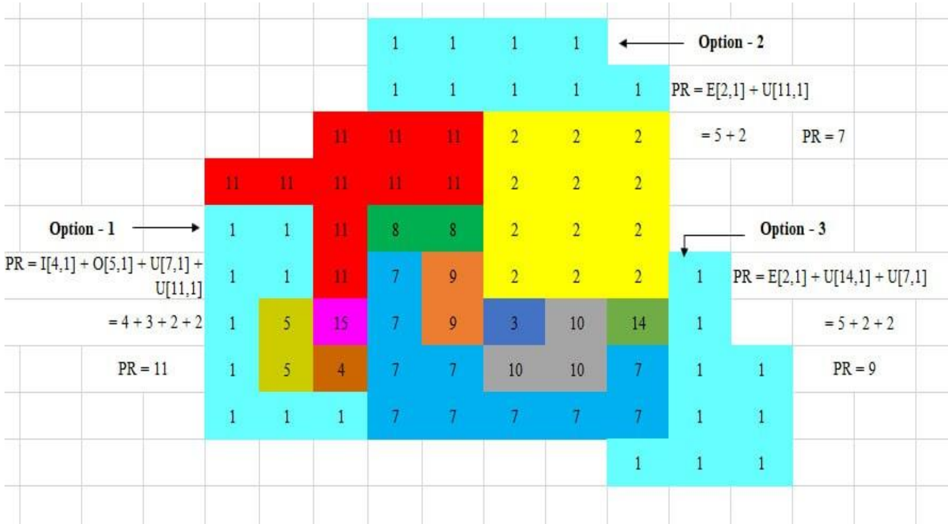


Figure 28: CORELAP Iteration 12

Three options were considered for the placement of department 1 and the one with the highest PR value of 11 is option 1 and the department will be placed on position 1.

Iteration – 13

The thirteenth department to be placed in the facility layout is department 12 (machinery cleaning and washing facility). The number of grids for the department is 1.

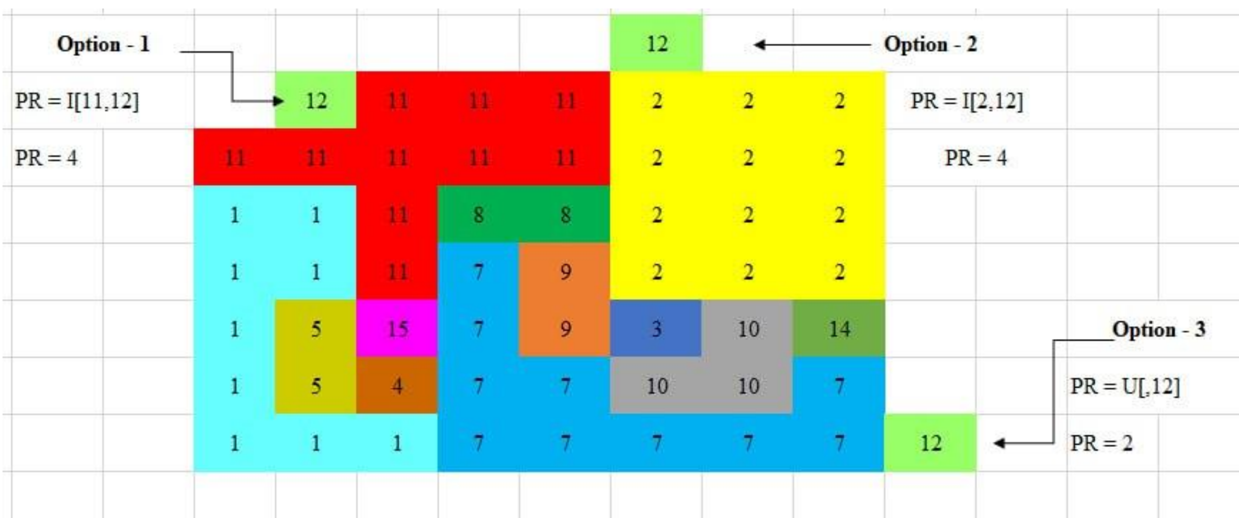


Figure 29: CORELAP Iteration 13

Three options have been selected for the placement of the department. Out of the three, option 1 and 2 have the largest PR value. Both positions are acceptable for the placement of the department and for this case, option 1 has been selected.

Iteration – 14

The fourteenth department to be placed is department 6 (general storage). This department is used for storing reusable materials, removed parts and other useful materials. Different options have been analyzed for obtaining the proper placement of the department. The number of grids for the department is 2.

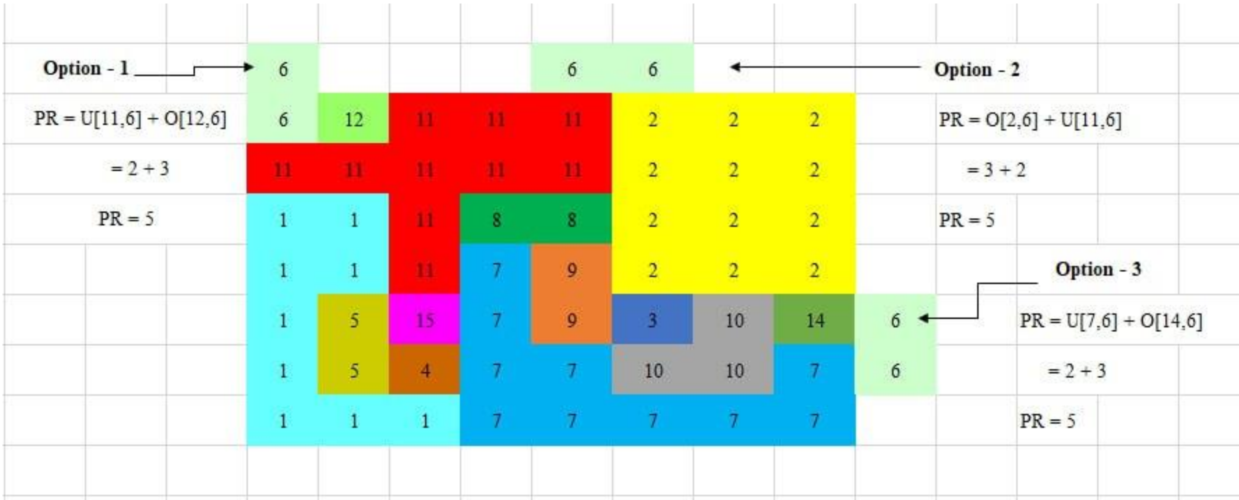


Figure 30: CORELAP Iteration 14

Three options have been analyzed for the position of the department and all three options have the same PR value, meaning all three positions are suitable for the placement of the department. Considering the relationship of the departments, option 2 has been selected for the placement of the department.

Iteration – 15

The last department to be placed in the newly constructed facility layout is department 13 (metal and fabrication shop). This department is placed last because it has an X relationship with two departments. And according to the procedures of CORELAP, if a department has an X relationship with a department it will be placed last.

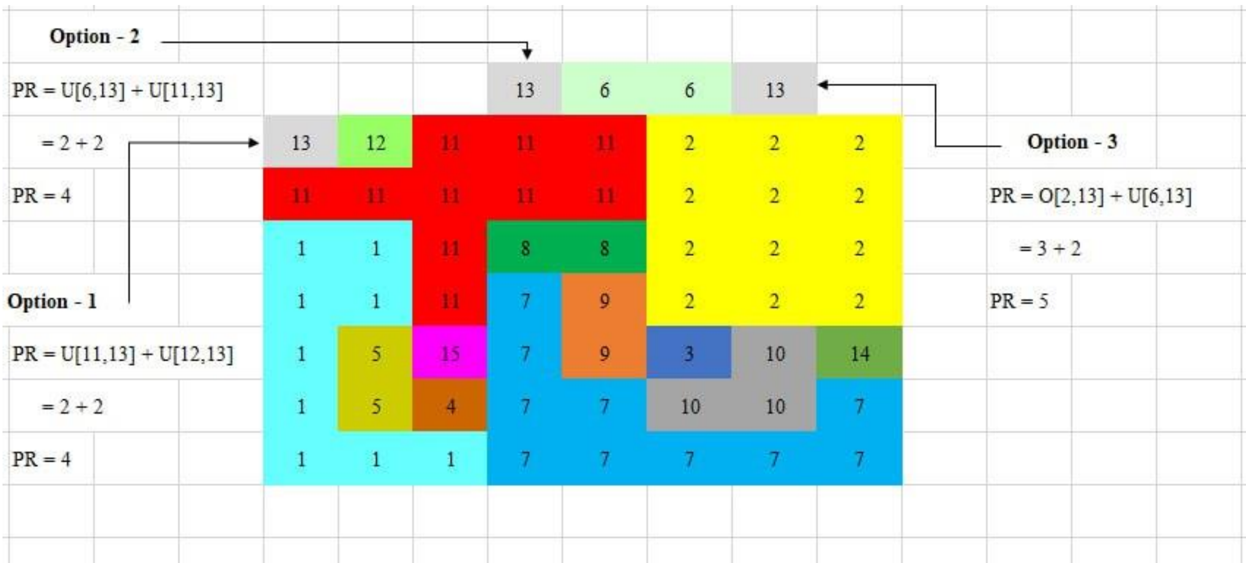


Figure 31: CORELAP Iteration 15

For the placement of the last department, three options were analyzed and according to the highest PR value of 5, option 3 has been selected for the placement of the metal and fabrication shop department.

After the iterations and the placement of all 15 departments based on the largest PR value, the complete facility layout of the agricultural machinery maintenance facility, constructed using the CORELAP layout development technique is as shown below.

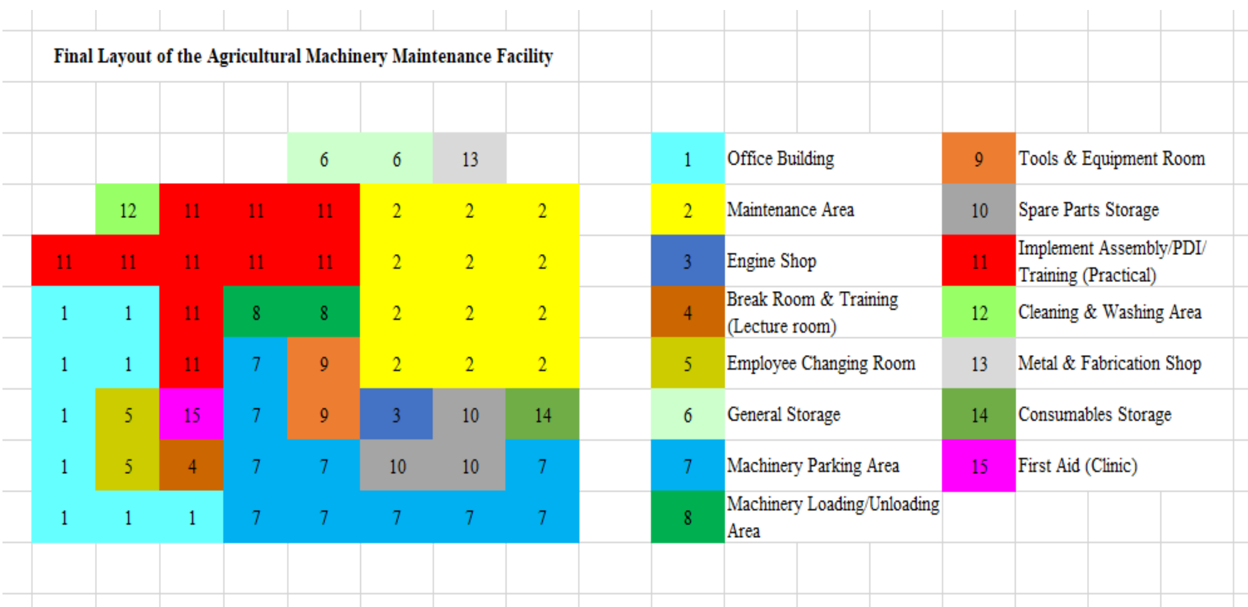


Figure 32: Final facility layout developed by CORELAP technique

4.4.2 Results of the Constructed Facility Layout

The CORELAP layout modeling technique tries to optimize the arrangement of different areas, departments and departments in a facility. Beside the configuration of the layout, another output of the method is improving travel distance. And in order to identify the rectilinear distance between the different departments the centroid values will be used and the up to scale centroid values along with their departments is shown in the table below.

Table 15: Rectilinear Distance between Departments

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	67.5	45	18.9	6.4	65	44.89	40	37.5	53.89	32.99	25	80	65	15
2	67.5	-	22.5	57.5	65	27.5	33.49	27.5	30	19.17	39.51	57.5	12.5	22.5	52.5
3	45	22.5	-	35	42.5	30	10.99	25	12.5	9.99	42.01	60	35	20	30
4	18.9	57.5	35	-	12.5	55	26.33	30	27.5	38.33	22.99	35	70	55	5
5	6.4	65	42.5	12.5	-	62.5	38.49	37.5	35	47.49	30.49	22.5	77.5	62.5	12.5
6	65	27.5	30	55	62.5	-	30.99	25	27.5	39.99	32.01	40	15	50	50
7	44.89	33.49	10.99	26.33	38.49	30.99	-	25.99	13.49	14.32	43	60.99	45.99	30.99	30.99
8	40	27.5	25	30	37.5	25	25.99	-	12.5	34.99	17.01	35	40	45	22.5
9	37.5	30	12.5	27.5	35	27.5	13.49	12.5	-	22.49	29.51	47.5	42.5	32.5	22.5
10	53.89	19.17	9.99	38.33	47.49	39.99	14.32	34.99	22.49	-	52	69.99	31.67	16.67	39.99
11	32.99	39.51	42.01	22.99	30.49	32.01	43	17.01	29.51	52	-	17.99	47.01	62.01	17.99
12	25	57.5	60	35	22.5	40	60.99	35	47.5	69.99	17.99	-	55	80	30
13	80	12.5	35	70	77.5	15	45.99	40	42.5	31.67	47.01	55	-	35	65
14	65	22.5	20	55	62.5	50	30.99	45	32.5	16.67	62.01	80	35	-	50
15	15	52.5	30	5	12.5	50	30.99	22.5	22.5	39.99	17.99	30	65	50	-
													Total Travel Distance between Departments		**3,871.92 m**

The travel distance between departments of the maintenance facility is 6,364 meters for the existing layout and 3.871.92 meters. Compared to the existing facility layout, that is a reduction of around 2,493 meters in travel distance for the facility layout that has been constructed using CORELAP facility layout modeling technique.

4.5 Application of CRAFT Layout Improvement Model (Optimization)

Once the new facility layout has been constructed using the CORELAP layout development technique, it will undergo through an optimization process to further enhance the layout using the CRAFT method.

In actual, the length of the newly constructed maintenance facility layout has a length of 64 meters and a width of 50 meters, and entering that into the facility information modal window will give us an area of 3,200 m^2.

Facility Information

Scale-m/unit	1	Cells
Length-m	64	64
Width-m	50	50
Area-sq.m	3200	3200

Figure 33: Facility Information

In the department information filling table, the maintenance facility departments along with the designated area in the layout will also filled and the program will automatically allot number of cells for each department. The department information table is described in the below figure.

Department Information

	Name	F/V	Area	Cells
Dept. 1	D 1	V	450	450
Dept. 2	D 2	V	600	600
Dept. 3	D 3	V	50	50
Dept. 4	D 4	V	50	50
Dept. 5	D 5	V	100	100
Dept. 6	D 6	V	100	100
Dept. 7	D 7	V	500	500
Dept. 8	D 8	V	100	100
Dept. 9	D 9	V	100	100
Dept. 10	D 10	V	150	150
Dept. 11	D 11	V	500	500
Dept. 12	D 12	V	50	50
Dept. 13	D 13	V	50	50
Dept. 14	D 14	V	50	50
Dept. 15	D 15	V	50	50

Figure 34: Department Entering Modal Window

The flow between the departments in the maintenance facility is as show in figure 28 below.

Flow Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
D 1	-	8.056		0.528			0.417				0.528				
D 2	8.056	-	0.333			2.083		16.222	16.222	12.028	3.000		2.167	4.639	
D 3		0.333	-						0.972	0.333					
D 4	0.528			-											
D 5					-										
D 6		2.083				-					3.000				
D 7	0.417						-	24.722			8.500	3.750			
D 8		16.222					24.722	-			11.500				
D 9		16.222	0.972						-		11.500				
D 10		12.028	0.333							-					
D 11	0.528	3.000				3.000	8.500	11.500	11.500		-	3.417		0.444	
D 12							3.750				3.417	-			
D 13		2.167											-		
D 14		4.639									0.444			-	
D 15															-

Figure 35: Flow between Departments of the Newly Constructed Layout

The last data to be filled in the CRAFT improvement technique is the cost matrix. To find the cost matrix, the rectilinear distance between every department of the newly improved facility layout (Table 16) will be multiplied with the unit cost value or the material handling cost. As identified earlier, the material handling cost is 0.0108 Birr per meter for junior technicians, 0.0352 Birr per meter for senior mechanics and 4.085 Birr per meter for the forklift. Using the material handling costs, the travel distance will be multiplied with each cost to define the cost matrix in the CRAFT program.

Cost Matrix

TO

FROM	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
D 1	-	0.73	0.49	0.20	0.07	0.70	0.48	0.43	0.41	0.58	0.36	0.27	0.86	0.70	0.16
D 2	0.73	-	0.24	0.62	0.70	0.30	0.36	0.30	0.32	0.21	0.43	0.62	0.14	0.24	0.57
D 3	0.49	0.24	-	0.38	0.46	0.32	0.12	0.27	0.14	0.11	0.45	0.65	0.38	0.22	0.32
D 4	0.20	0.62	0.38	-	0.14	0.59	0.28	0.32	0.30	0.41	0.25	0.38	0.76	0.59	0.05
D 5	0.07	0.70	0.46	0.14	-	0.68	0.42	0.41	0.38	0.51	0.33	0.24	0.84	0.68	0.14
D 6	0.70	0.30	0.32	0.59	0.68	-	0.33	0.27	0.30	0.43	0.35	0.43	0.16	0.54	0.54
D 7	0.48	0.36	0.12	0.28	0.42	0.33	-	0.28	0.15	0.15	0.46	0.66	0.50	0.33	0.33
D 8	0.43	0.30	0.27	0.32	0.41	0.27	0.28	-	0.14	0.38	0.18	0.38	0.43	0.49	0.24
D 9	0.41	0.32	0.14	0.30	0.38	0.30	0.15	0.14	-	0.24	0.32	0.51	0.46	0.35	0.24
D 10	0.58	0.21	0.11	0.41	0.51	0.43	0.15	0.38	0.24	-	0.56	0.76	0.34	0.18	0.43
D 11	0.36	0.43	0.45	0.25	0.33	0.35	0.46	0.18	0.32	0.56	-	0.19	0.51	0.67	0.19
D 12	0.27	0.62	0.65	0.38	0.24	0.43	0.66	0.38	0.51	0.76	0.19	-	0.59	0.86	0.32
D 13	0.86	0.14	0.38	0.76	0.84	0.16	0.50	0.43	0.46	0.34	0.51	0.59	-	0.38	0.70
D 14	0.70	0.24	0.22	0.59	0.68	0.54	0.33	0.49	0.35	0.18	0.67	0.86	0.38	-	0.54
D 15	0.16	0.57	0.32	0.05	0.14	0.54	0.33	0.24	0.24	0.43	0.19	0.32	0.70	0.54	-

Figure 36: Unit Cost Matrix of the Newly Constructed Layout

After selecting the above options, the user will define the initial layout by filling the plant with the indices of the colors to determine the initial value of the facility layout and start the optimization process.

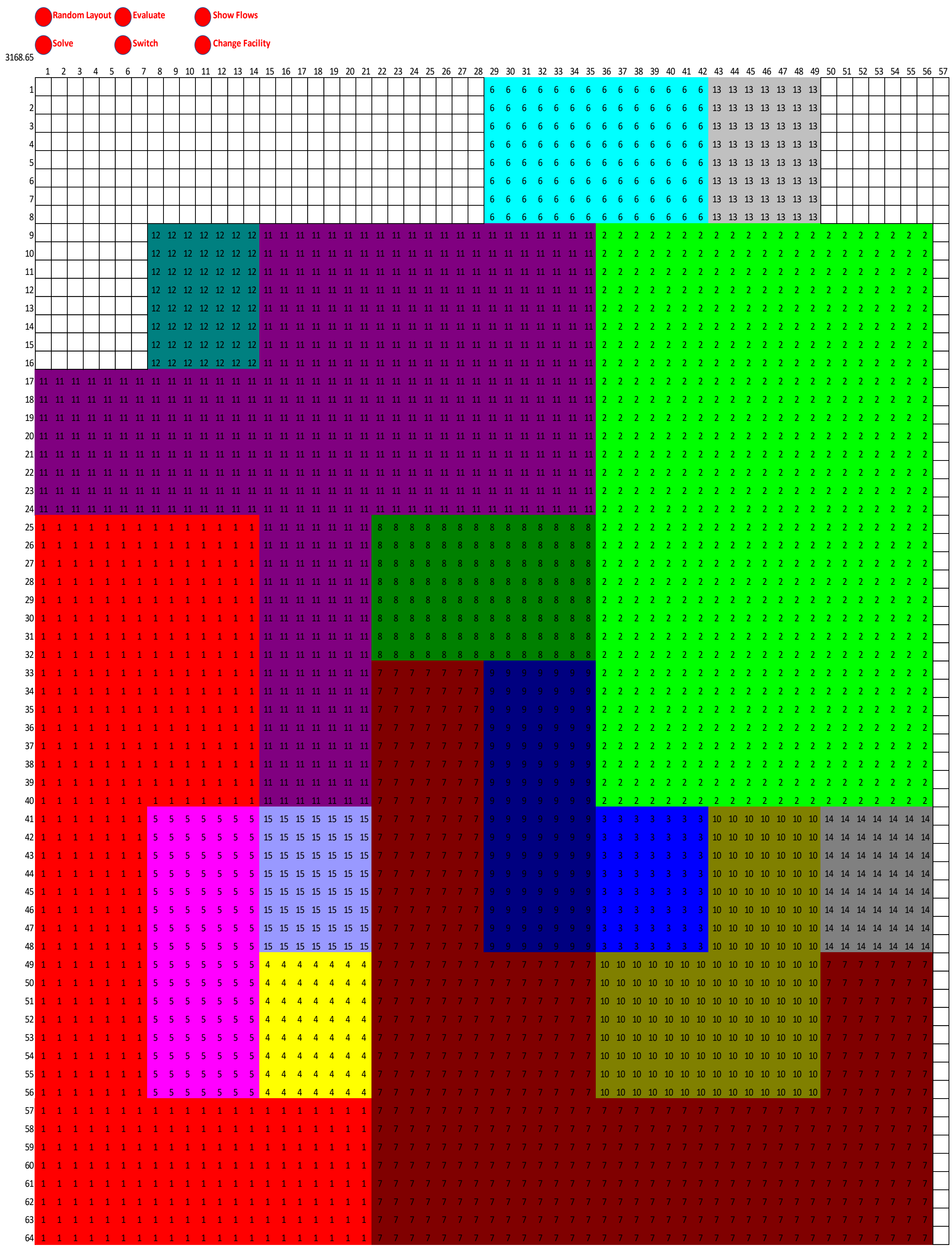


Figure 37: Defined Initial Layout

The defined initial layout has an initial cost of 3,169 birr, which is a reduction of around 5,934 birr from the existing layout. This by itself shows the improvement made by the CORELAP method but further optimization can still reduce the layout cost.

The next step would be to solve the defined initial layout to identify the cost of the layout and also make pairwise exchange between adjacent departments and departments with the same area. And this is done to decrease the cost of the layout by giving an optimal placement for the reduction of cost. Pressing solve from the range of optimization options will calculate the cost of the initial layout and goes through a step by step optimization process until the best layout option with reduced cost is achieved.

<u>Iteration – 1</u>

According to the CRAFT algorithm, the first best department switch suggestion that can decrease the cost of the layout by 512 Birr is a switch between department 2 (Maintenance Area) and 3 (Engine Shop).

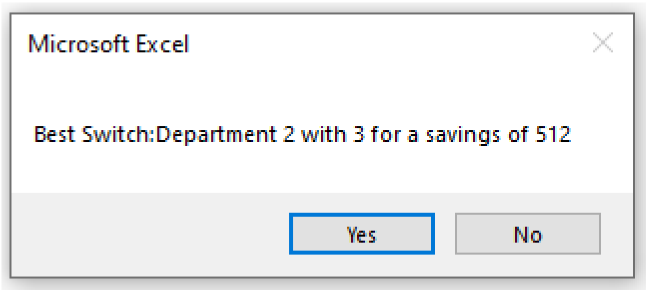


Figure 38: CRAFT Iteration 1

<u>Iteration – 2</u>

The second-best department switch suggested by the algorithm to reduce the cost is between department 7 (Machinery Parking) and 15 (First Aid/Clinic). The switch between the departments will save 408 Birr.

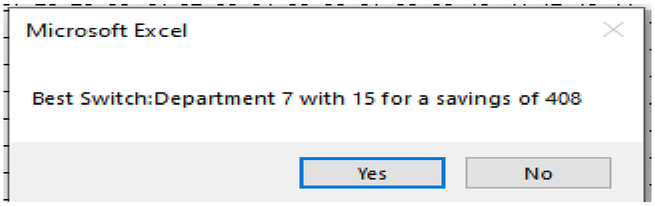


Figure 39: CRAFT Iteration 2

Iteration – 3

The third iteration that will decrease the cost and suggested by the algorithm is a switch between department 7 (Machinery Parking) and 11 (Implement Assembly/PDI/Practical Training Facility). The switch between the departments will save 380 Birr.

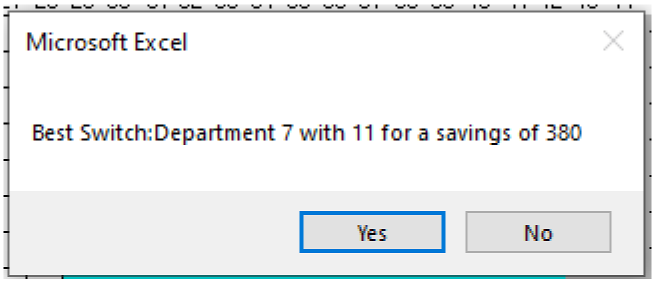


Figure 40: CRAFT Iteration 3

Iteration – 4

The next suggestion for best switch is between department 2 (Maintenance Area) and 9 (Tools & Equipment Room). The switch between the departments will save 222 Birr.

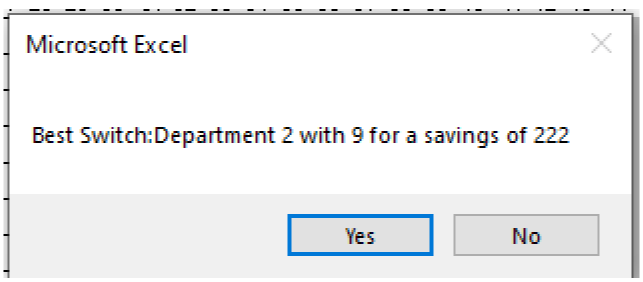


Figure 41: CRAFT Iteration 4

Iteration – 5 - 13

Overall iteration results and their respective cost from the CRAFT has been shown in the figure below.

Init. Cost 3169

Iterations: 13

Index	Init. Seq.	Iter.	Type	Action	Cost
1	1	1	Switc	2 and 3	3062
2	2	2	Switc	7 and 15	2946
3	3	3	Switc	7 and 11	2567
4	4	4	Switc	2 and 9	2565
5	5	5	Switc	2 and 11	2264
6	6	6	Switc	1 and 4	2219
7	7	7	Switc	9 and 14	2190
8	8	8	Switc	10 and 9	2111
9	9	9	Switc	14 and 15	2070
10	10	10	Switc	1 and 5	2060
11	11	11	Switc	13 and 15	2053
12	12	12	Switc	4 and 12	2049
13	13	13	Switc	1 and 14	2050
14	14				
15	15				

Figure 42: Iteration Results of CRAFT

The CRAFT layout improvement program suggested 13 best department switches that can decrease the cost of material handling. The program will continue suggesting best switches until the best layout is achieved or when the switch suggestion increases the cost of the material handling. In this iteration process, the last iteration actually increased the cost so the program stopped on the 13th iteration (switch between department 1 and 14) and took the 12th iteration result as the final result of the improvement as the final cost of the maintenance facility. Therefore, as determined by the program, the final result of the material handling cost is 2,049 Birr.

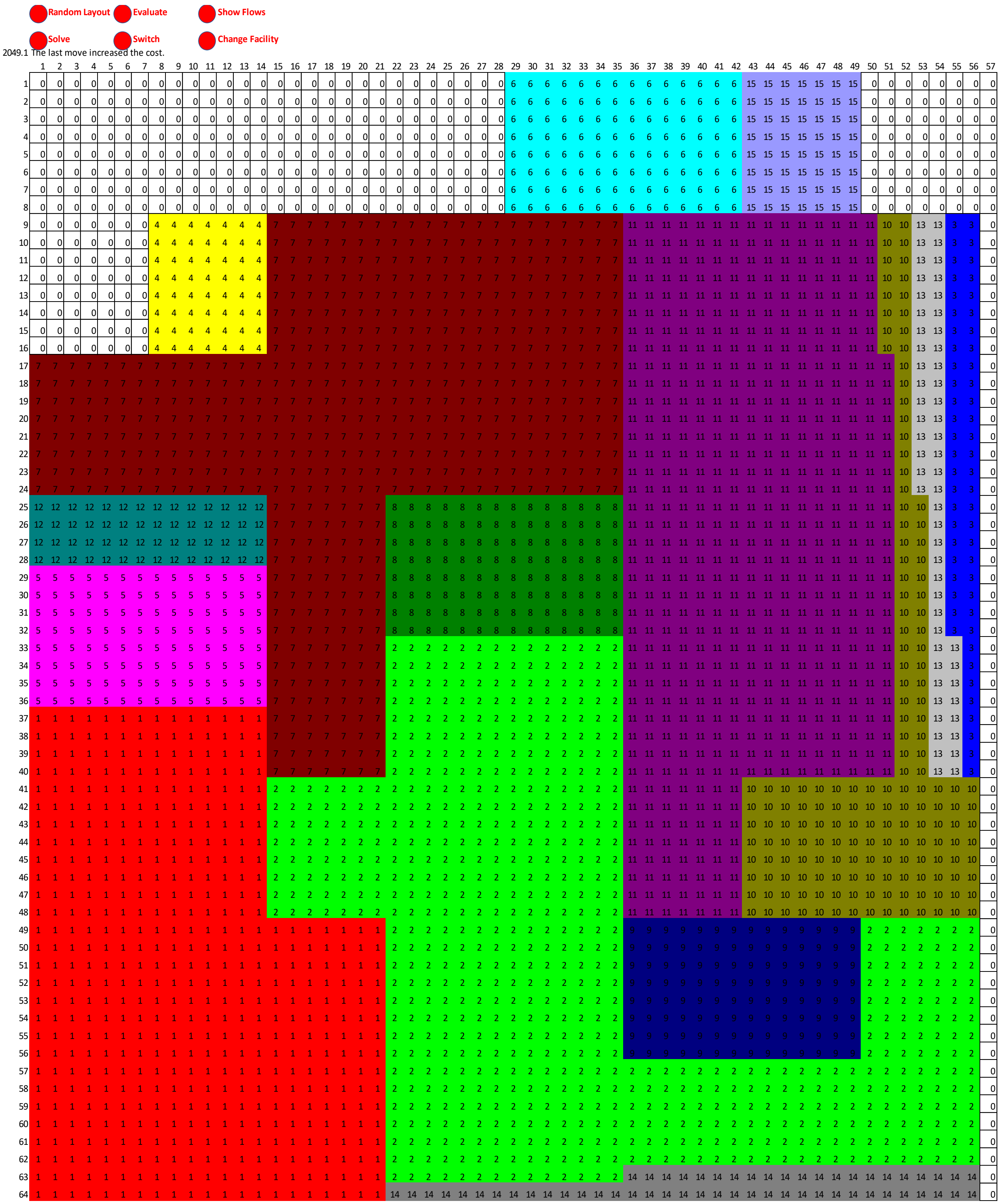


Figure 43: Output of CRAFT Layout Improvement

The above layout result from the excel add-in gives a material handling cost of 2,049 Birr. Which significantly reduced the cost of material handling. But as it can be seen for departments 3, 10, 13 and 14, some parts of the departments have a width of 1 & 2 meter, which is not ideal for the maintenance operation and the functionality of the maintenance facility in general.

CRAFT program works by interchanging departments and workstations based on their adjacency and area and this is to mean that departments are interchanged only if they are adjacent to each other or if they have an equal area. Sometimes the program can give an inappropriately rearranged departments that are not ideal for the work place or the placement of the department in general. This means that CRAFT can't always provide an optimal layout but it provides a near optimal result that can be modified in a heuristic way (Mebrat et al., 2020). An optimal result can be achieved by involving experts in the decision making and relying on their experience. Therefore, as CRAFT doesn't always give an optimal result, the layout should be improved further based on the near optimal result of the program. To solve the issues with the optimized layout and have an optimum layout that considers the relationship between departments, a focus group discussion has been applied to have an expert say in the situation.

A focus group discussion involving 6 participants, one expert from management (maintenance head) with a qualification of a BSc in Automotive maintenance and 15 years' experience in the agricultural machinery maintenance industry, one Industrial engineer with 3 years of experience and 4 technicians with a qualification from Technical and Vocational Education and Training institutes and with an average experience of 10 years, has been conducted.

In the focus group discussion, the first question raised is if there are any department placements that are illogical or could be improved based on real world workflow considerations. The points addressed on this topic, as discussed earlier, some departments (3, 10, 13 and 14) have a space that is narrow for the different activities of the departments. These areas will lead to difficulties in maneuvering equipment's and materials, limited storage capacity and this limited space can lead to congestion and bottlenecks in the workflow. Regarding this issue, the participants agreed that these departments should have a proper department shape for maneuverability and storage. Another point raised is that department 8 (machinery loading/unloading) should not be in the middle of the layout, but rather on the side without other departments interfering with its operation and also for the loading/unloading operation not to disturb the other activities of the maintenance facility. Also, department 15 (first aid/clinic) should be placed in an area of the maintenance facility where there is less work activity and disturbance and also should be an ideal spot for all the departments to access it with ease.

The next point raised is to identify if there are any departments that require frequent interaction but are placed apart and also if there are any departments that should not be placed together. The key points raised by the technicians here is that department 3 (engine shop) should be next to department 2 (maintenance area) and this is done so as to simplify the movement of engines that need overhauling and to install engines that have been overhauled in the maintenance area. Regarding department 9 (tools and equipment room), it has a frequent interaction with the department 2 (maintenance area) and should be placed next to or near the maintenance department. Also, it was pointed out that department 9 (tools and equipment) and department 10 (spare parts storage) should be placed close to each other for convenient access during repairs. And due to safety considerations, department 14 (consumables storage) and department 13 (metal and fabrication) should not be close to each other as consumable storage is often used to store flammable materials, it should be positioned from any areas that may generate sparks or any other potential ignition source like the metal and fabrication shop.

The third point raised in the focus group discussion is if the size and capacity of each departments is appropriate for the anticipated work load and storage requirements. Small working areas create challenges in the maintenance activities and also having departments constrained by space will limit future growth and expansion in the service capabilities. As having sufficient working area makes it easy for the technicians to work freely and perform certain tasks with ease and also as it is safe and easy to monitor and control the facility, the participants agree and support the idea of having a sufficient working space that also has room for future expansion based on the future work load and that size and capacity of the departments is an issue in the layout.

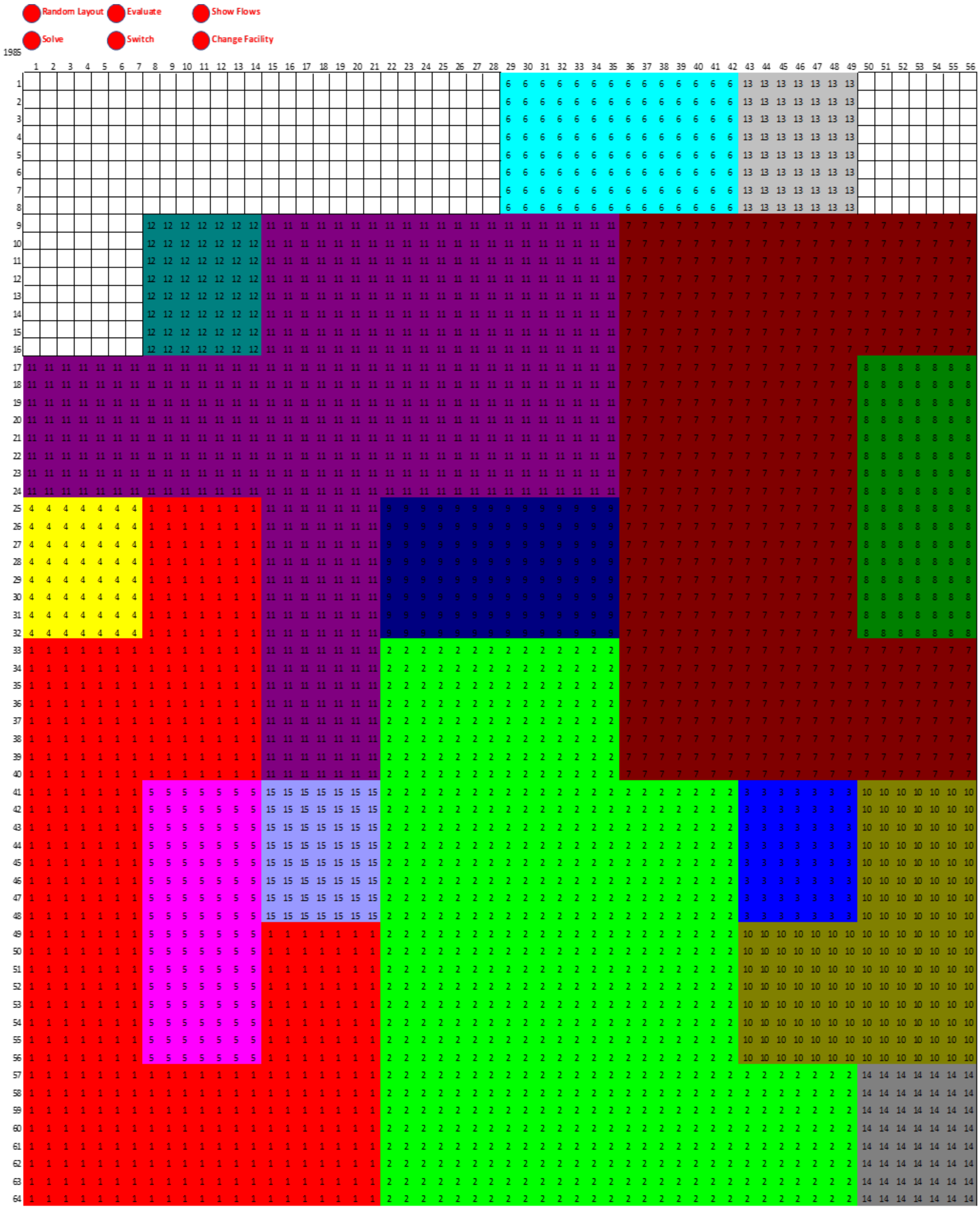


Figure 44: Proposed Agricultural Machinery Maintenance Facility Layout

Based on the discussion points, expert opinion and experience, the facility layout has been improved and the focus group participants were involved in the actual improvement of the layout. The final layout of the agricultural machinery maintenance facility is shown in the figure below. The final result of the technicians and forklift total monthly material handling cost of the proposed layout is 80,370.86 Birr.

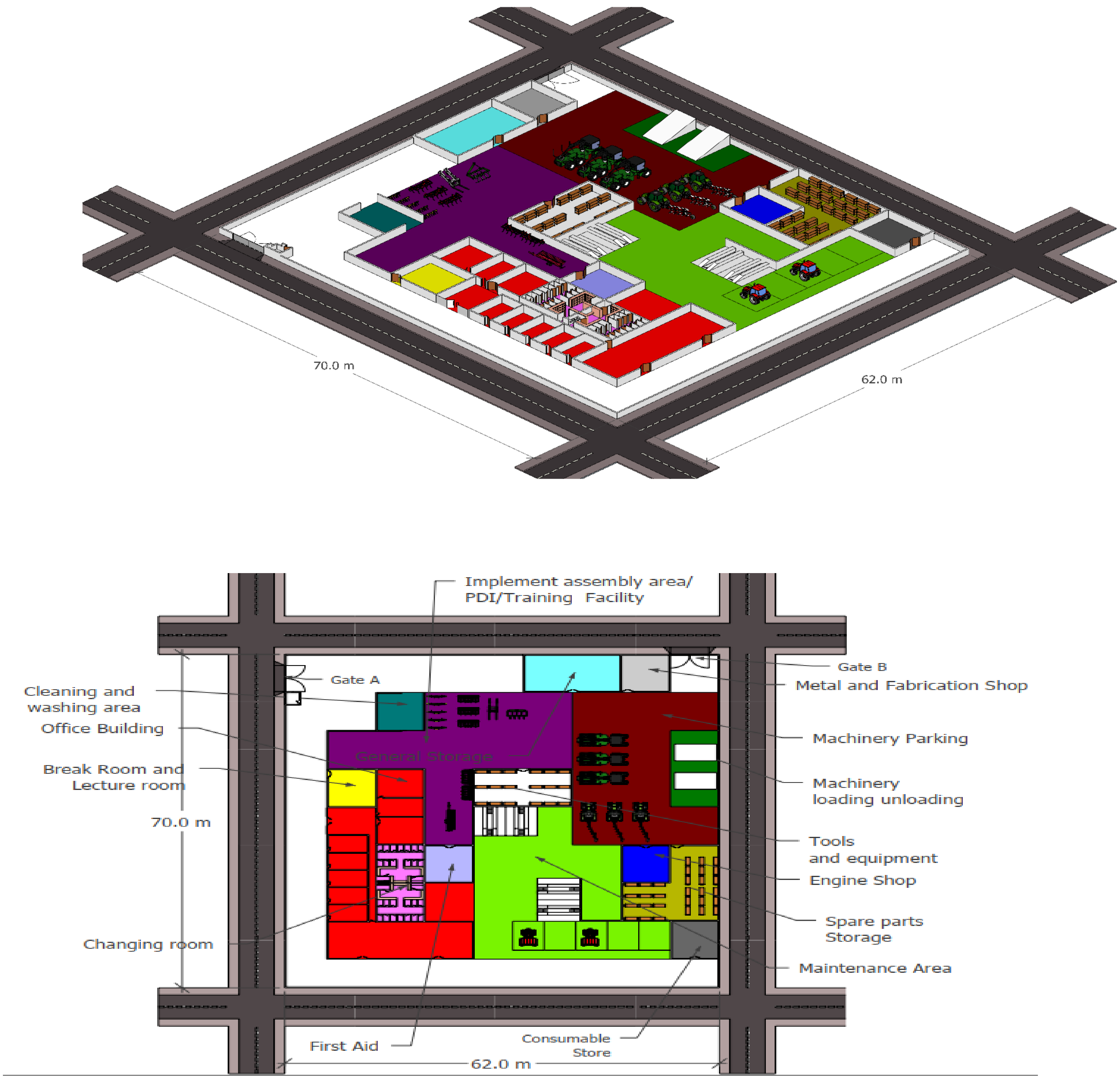


Figure 45: Proposed Facility Layout

Centroid of Optimized Layout

The CRAFT will automatically generate the departments position using the x and y centroid values. Each department along with their designated color, department area and centroids are presented in the table below.

Table 16: Location of proposed Facility Layout

Department	Color Indicator	Area in m^2	x-centroid	y-centroid
OB	1	450 m^2	8.94	47.55
MA	2	600 m^2	32.08	50
ES	3	50 m^2	45.5	44
BR	4	50 m^2	3.5	28
CR	5	100 m^2	10.5	48
GS	6	100 m^2	35	4
MP	7	500 m^2	44.09	24
ML/U	8	100 m^2	52.5	24
T&E	9	100 m^2	28	28
SS	10	150 m^2	50.16	49.33
IA/PDI	11	500 m^2	19.60	20
C&W	12	50 m^2	10.5	12
MS	13	50 m^2	45.5	4
CS	14	50 m^2	52.5	60
FA	15	50 m^2	17.5	44

Table 17: Rectilinear Distance between Departments of the proposed layout

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	25.59	40.11	24.99	2.01	69.61	58.7	67.11	38.61	43	38.21	37.11	80.11	56.01	12.11
2	25.59	-	19.42	50.58	23.58	48.92	38.01	46.42	26.08	18.75	42.48	59.58	59.42	30.42	20.58
3	40.11	19.42	-	58	39	50.5	21.41	27	33.5	9.99	49.9	67	40	23	28
4	24.99	50.58	58	-	27	55.5	44.59	53	24.5	67.99	24.1	23	66	81	30
5	2.01	23.58	39	27	-	68.5	57.59	66	37.5	40.99	37.1	36	79	54	11
6	69.61	48.92	50.5	55.5	68.5	-	29.09	37.5	31	60.49	31.4	32.5	10.5	73.5	57.5
7	58.7	38.01	21.41	44.59	57.59	29.09	-	8.41	20.09	31.4	28.49	45.59	21.41	44.41	46.59
8	67.11	46.42	27	53	66	37.5	8.41	-	25.5	27.67	36.9	54	27	36	55
9	38.61	26.08	33.5	24.5	37.5	31	20.09	25.5	-	43.49	16.4	33.5	41.5	56.5	26.5
10	43	18.75	9.99	67.99	40.99	60.49	31.4	27.67	43.49	-	59.89	77	49.99	13.01	37.99
11	38.21	42.48	49.9	24.1	37.1	31.4	28.49	36.9	16.4	59.89	-	17.1	41.9	72.9	26.1
12	37.11	59.58	67	23	36	32.5	45.59	54	33.5	77	17.1	-	43	90	39
13	80.11	59.42	40	66	79	10.5	21.41	27	41.5	49.99	41.9	43	-	63	68
14	56.01	30.42	23	81	54	73.5	44.41	36	56.5	13.01	72.9	90	63	-	51
15	12.11	20.58	28	30	11	57.5	46.59	55	26.5	37.99	26.1	39	68	51	-
										Total Travel Distance between Departments				**4,348.89 m**	

Using the centroid data from the CRAFT algorithm, the total rectilinear travel distance between the departments of the optimized agricultural machinery maintenance facility layout is 4,348.89 meter.

4.6 Proposed Facility Layout Simulation Modeling

For the representation of the proposed facility layout in Arena, just like the existing layout, only crucial models that affect the throughput and process time are represented. In comparison with the existing layout, the proposed layout has departments that are flexible and serve different tasks. The break room is also used as a lecture room for farmalization trainings and the PDI, implement assembly and practical training facilities share the same area as the job request for the respective departments is seasonal. Also, when specifically looking at the practical trainings given in the maintenance facility, they are held for a few times in a year and their effect is very minimal to consider in the modeling.

The simulation was replicated for 42 times with a simulation period of 1,235 hours for each replication. As observed from the report, the throughput of the model is 67 units. And the average process time of the 42 replications for the proposed facility layout is 47,399.93. The process time compared to the existing facility its higher and this is because the number of processed orders is greater than the existing layout output. The proposed facility layout only has a queue at the parking department. This department uses a resource of 35 parking areas; therefore, this shows that there are about 23 machineries waiting to be parked.

The simulation modeling of the proposed agricultural machinery maintenance facility is shown in the figure below.

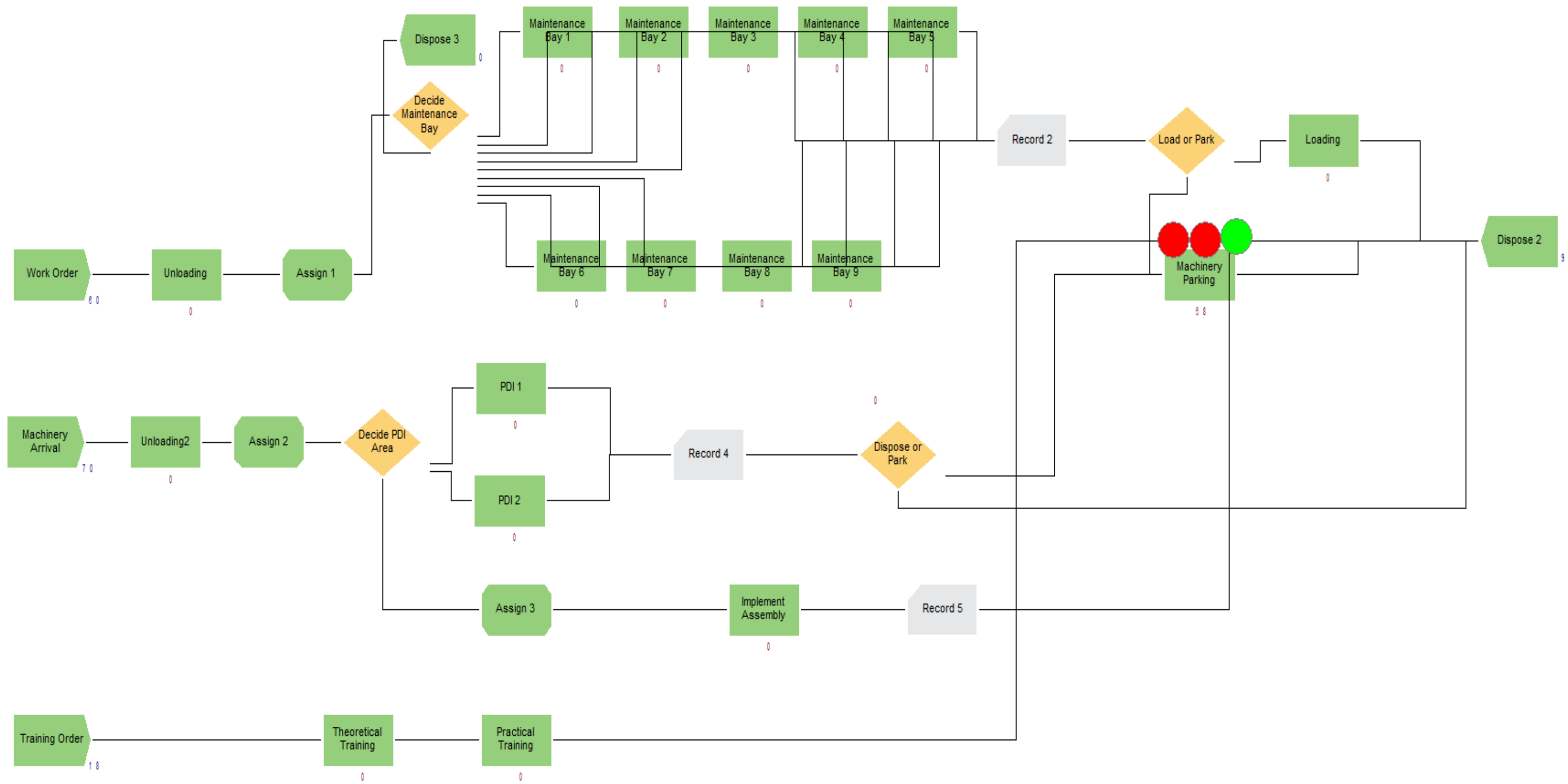


Figure 47: Simulation Modeling of the Proposed Layout

4.7 Result and Discussion

In this section the results from the facility layout construction, improvement, simulation results and also the theoretical and practical implication of the study are presented.

First, focusing on the facility layout and using the values for the existing and proposed layout, the percentage improvement for both the distance travelled and monthly material handling cost is:

The percentage reduction of distance for the proposed layout is:

$$= \frac{Existing\ Layout\ Travel\ Distance - Proposed\ Layout\ Travel\ Distance}{Existing\ Layout\ Travel\ Distance}\ X\ 100\%$$

$$= \frac{6364 - 4348.89}{6364}\ X\ 100\%$$

$$\underline{\underline{= \mathbf{31.66}\ \%}}$$

This shows that the total distance travelled in the proposed facility layout is reduced by 2,015.11 meter and that is a reduction of 31.66% compared to the travel distance of the existing facility layout.

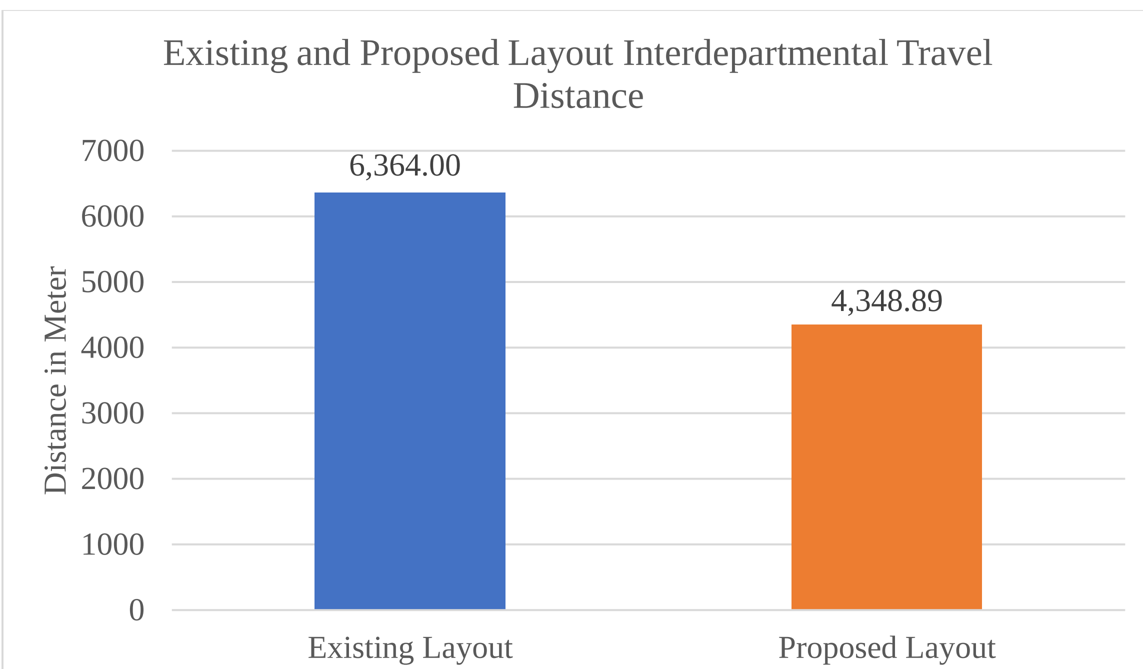


Figure 46: Interdepartmental Travel Distance

The percentage reduction of the total material handing cost of the proposed layout is:

$$= \frac{Existing\ Layout\ Cost - Proposed\ Layout\ Cost}{Existing\ Layout\ Cost}\ X\ 100\%$$

$$= \frac{611{,}434 - 80{,}370.86}{611{,}434}\ X\ 100\%$$

$$\underline{\underline{= \mathbf{86.85}\ \%}}$$

This shows that the material handling cost in the proposed facility layout is reduced by 531,093.14 Birr and that is 86.85% reduction compared to the existing maintenance facility layout.

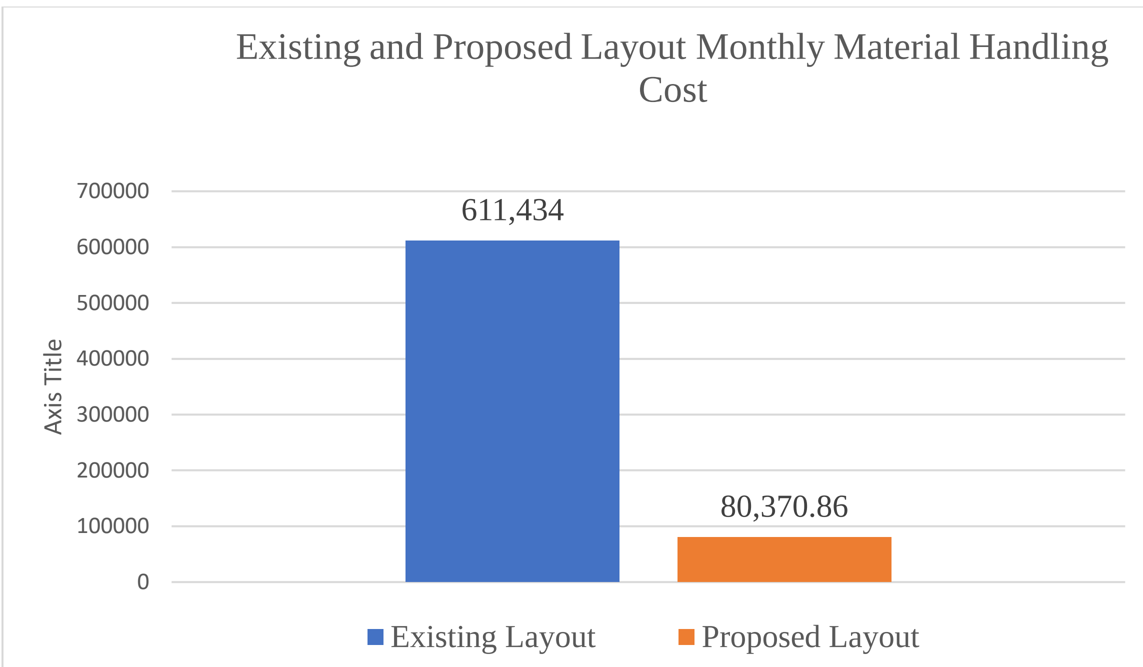


Figure 47: Monthly Material Handling Cost

This reduction in travel distance, material handling cost, process time and increase in the throughput of the maintenance facility are the result of the integration of supporting facilities in the operation of the maintenance facility.

For the result of the existing and proposed layout modeling simulation result, the results are summarized in the table below using selected key performance indicators.

Table 18: Analysis results of Existing and Proposed Layout

Simulation Results of 42 Replication Runs				
	Existing Layout	**Proposed Layout**	**% Improvement**	**Remark**
Entity				
Entity In	148	148	-	
Entity Out	40	67	67.5%	
Process Time				
Handling Time	31,100.94	47,399.93	52.40% increase	Increase in process time due to 67.5% increase in the unit output.
Throughput				
System Output	125.30	199.04	58.85%	

4.7.1 Theoretical Implication

The study conducted on layout modeling and optimization of an agricultural machinery maintenance facility using discrete event simulation has several theoretical implications that can be used for future studies as an input and methodological reference in studies related to facility layout development and maintenance facilities. The study tries to show the significance of supporting facilities in maintenance facilities, as these facilities enhance the workflow which in return will reduce bottlenecks, time and cost for the facility.

4.7.2 Practical Implication

The practical implication of the study is mainly for the case company, Wereta International Business Plc. For the case company, by incorporating and optimizing storage areas, tools room, metal and fabrication shop, and cleaning and washing facilities, the company can achieve significant improvement in the efficiency of the maintenance facility. Additionally, creating a well-designed and organized maintenance facility and incorporating supporting facilities benefits the company in so many ways, including enhanced efficiency, cost savings, employee productivity and customer satisfaction.

Chapter Five

5. Conclusion and Recommendation

5.1 Conclusion

The objective of this study is to develop and optimize a maintenance facility layout for an agricultural machineries and DES is used for validation of the results. Based on the analysis of the existing layout of the facility, it's concluded that:

- The design of the facility layout, including main and supporting facilities were not well-designed and created a long travel distance between departments which affect the workflow efficiency of the facility. Also, the current infrastructure capacity of the facility affected the process time of tasks and the overall throughput of the facility, thus creating long queues in the maintenance and PDI operation.
- An area for improvement is the travel distance between departments. Regarding this issue, the relationship between departments was analyzed and a layout that considers interdepartmental relationship was constructed using CORELAP and further optimized using CRAFT excel add-in tool. The travel distance has been reduced to 4,348.89 meter and compared to the existing layout travel distance of 6,364 meter, it's a reduction of 31.66% in total travel distance. This reduction of travel distance will improve the workflow and efficiency of the facility.
- As evaluated by the CRAFT tool, the existing layout has a total material handling cost of 611,434 Birr per month and the proposed layout has a monthly material handling cost of 80,370.86 Birr, which is a reduction of 86.85%. This shows that the distance between departments is costing the company greatly.
- Arena simulation modeling of the existing and proposed layout was conducted and regarding process time and total throughput, the proposed facility layout showed improvement over the existing layout. Therefore, constructing a new layout and then followed by an optimization procedure has several benefits including incorporation of new departments, improvement in the process time and throughput and overall efficiency of the facility.

5.2 Recommendation

According to the analysis conducted for the existing and proposed facility layouts, the following recommendations have been forwarded:

- The long travel distance between departments, especially the departments outside the compound of the maintenance facility, implement assembly and spare parts storage, are leading to less employee productivity, increased material handling cost, increased process time and reduced throughput, which in return leads to an inefficient workflow and performance in the facility. So, it is recommended that the main and supporting facilities with frequent interaction should be close to each other.
- With the current vision and mission of the case company, it is better to construct a new facility layout rather than improving the existing one. And this is due to the unfulfilled infrastructural requirements and also the less operational capacity of the facility. In the case of constructing a new facility layout, the case company should apply similar procedures and approaches described in the study.

5.3 Future research Areas

The following research areas are recommended for future research areas in the agricultural and other vehicle maintenance industries.

- One of the features of the fourth revolution of industry, Industry 4.0, is digital twin modeling. Incorporating it with facility layout modeling and having the digital model of the facility will help in identifying bottlenecks, running simulations, configuration of the layout and helps stakeholders in decision making. Thus, it’s recommended that researchers try to address this in future studies.
- The human factor and ergonomics topic is almost present in every work operation. Maintenance facilities, whether machinery or vehicle, should have a safe and productive working area. Therefore, further studies should be conducted in integrating human factor and ergonomics with facility layout development for more safe and conductive work environment.

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Annex

Annex 1: Pre-Delivery Inspection Form

AGT PRE-DELIVERY INSPECTION (PDI) REPORT
AGRICULTURAL TRACTORS

CASE IH

UNIT DETAILS

Model	Serial No.	Dealer name
Dealer code	Dealer Country	
Date of Inspection	Technician name	

TECHNICIAN REPORT TABLE

ITEM N. (1-122)	FAULT (1-6)	Brief, but specific, description of unsatisfactory condition	Corrective action / repair order / claim no

Number of Attachments: ____

FAULTS	1. INOPERATIVE PART	2. OMITTED PART	3. INCORRECT PART
	4. DAMAGED PART	5. INCORRECTLY FITTED/FILLED	6. CONTAMINATED

6-66120EX (Pack of 10)

PDI REPORT – AGRICULTURAL TRACTORS

		Check OK	Check X	Comments
	EXAMPLES			
A	If the item is OK, put	✓		and leave the X column empty
B	If the check is Not Applicable, put	**NA**		and leave the X column empty
C	If you fix a problem, put	✓	**X**	and fill the Technician report table (p.1)

Check the operation/function/condition of the various components/systems of the machine.

		Check OK	Check X	Comments
	PRE START UP CHECKS (levels)			
1	Lubricate all grease points			
2	Engine oil			
3	Coolant			
4	Brake oil / fluid			
5	Clutch fluid			
6	Transmission oil			
7	Power steering fluid			
8	Front axle oil			
9	Front hubs / final drive oil (LH, RH)			
10	Rear Axle oil			
11	Battery (voltage)			
12	Tyres (pressure)			
	DYNAMOMETER TEST			
	in this section !ONLY! insert readings and measure units			
	Temperature gauge reading			
	Idle speed (rpm)			
	Max. no load (rpm)			
	Max. PTO power			
	Max. torque			
	ENGINE - Section 10			
13	Cold start system			
14	Safety start			
15	Ease of starting			
16	Ease of stopping			
17	Oil pipes			
18	Oil filter & housing			
19	Exhaust			
20	Air intake			
21	Air filters / pre cleaners			
22	Drive belt(s) - tension			
	Fuel system			
23	Tank / filler cap / taps			
24	Fuel lines			
25	Fuel filters / water separator			
26	Fuel injection pump			
27	Fuel lift pump			

		Check OK	Check X	Comments
	ENGINE - Section 10 (continued)			
	Cooling system			
28	Radiator			
29	Hoses			
	TRANSMISSION - Section 21			
30	Clutch operation			
31	Clutch calibration completed			
32	Gear selection			
33	Shuttle			
34	Transmission / rear axle joint			
35	Transmission housing			
36	Oil filters and housing			
37	Oil pipes / hoses			
38	Oil cooler			
	FRONT MECHANICAL DRIVE - Section 25			
39	Front axle centre housing			
40	Axle / hub oil seals			
41	Differential lock			
42	4WD engagement			
43	Oil supply pipes			
	REAR DRIVE AXLE - Section 27			
44	Axle casing			
45	Differential lock			
	IMPLEMENT POWER TAKE-OFF - Section 31			
46	Power take off			
	BRAKES AND CONTROLS - Section 33			
47	Footbrake			
48	Handbrake			
49	Trailer brakes			
50	Trailer brake sys. pressure			
51	Pipes / hoses			
	HYDRAULIC SYSTEMS - Section 35			
52	Hydraulic lift (mechanical)			
53	EDC valve / system			
54	Lift calibration completed			
55	Automatic Pick-Up Hitch			
56	Drawbar			
57	Top cover / cross shaft			
58	PTO - front			
59	Main hydraulic pump			
60	Auxiliary pump			
61	Hydraulic filters & housing			

PDI REPORT – AGRICULTURAL TRACTORS

No.	Item	Check OK	Check X	Comments
	HYDRAULIC SYSTEMS - Section 35 (continued)			
62	Lift / assist cylinder(s)			
63	Max. pressure at remotes			
64	Flow at remotes			
65	Pipes / hoses / cylinders			
	STEERING - Section 41			
66	Steering linkage / alignment			
67	Stops (steering angle)			
68	Pipes / hoses / cylinders			
	AXLES AND WHEELS - Section 44			
69	Wheel bearings			
70	Wheel / rim bolt torques			
71	Rim / axle bolt torques			
	CAB CLIMATE CONTROL - Section 50			
72	Air conditioning			
73	Heating / ventilation			
	ELECTRICAL SYSTEMS - Section 55			
74	Side / licence plate lights			
75	Headlights main/dip			
76	Worklights			
77	Cab interior lights			
78	Directional left / right / hazard lights			
79	Stop lights			
80	Screen wash (front / rear)			
81	Screen wipe (front / rear)			
82	Switches			
83	Horn			
84	Handbrake warning			
85	Trailer Socket/aux power point			
86	Instrument panel / gauges			
87	Clock			
88	Ground drive PTO interlock			
89	Performance monitor/radar			
90	PTO warning light			
	PLATFORM, CAB, BODYWORK AND DECALS - Section 90			
	Internal			
91	Hand throttle controls / switch			
92	Foot throttle controls			
93	Levelling box control			
94	Windows / seals			
95	Doors / seals			
96	Door locks			

No.	Item	Check OK	Check X	Comments
	PLATFORM, CAB, BODYWORK AND DECALS - Section 90			
	Internal (continued)			
97	PTO speed selection			
98	Escape hatch			
99	Hydraulic controls			
100	Sun visor			
101	Seat			
102	Operator's manual			
103	Certification plate			
104	Trim / mats			
105	Internal fittings			
	External			
106	Mirrors (external)			
107	Tool box			
108	Fenders			
109	Washer Bottle			
110	Cab roof / hard top			
111	Decals			
112	Plated parts			
	Paint			
113	Cab / platform / ROPS			
114	Engine			
115	Final drive housing			
116	Front axle / hubs			
117	Front weights / axle support			
118	Hood / radiator grill			
119	Lift cover / arms / linkage			
120	Rear axle / hubs			
121	Transmission			
122	Wheels / discs / rims			

Checked item 122 of 122, now complete the Technician report table (page 1)

PDI REPORT – AGRICULTURAL TRACTORS

PROCEDURAL GUIDELINES

STEPS TO FOLLOW

I. Complete the "**Unit details**" (page 1).

II. Complete the "**Pre Start Up Checks**" before the machine is started or run. Failure to do this may result in serious machine damage.

III. Complete the "**Dynamometer tests**" if the equipment is available. If this is not possible, operate the unit until all components / lubricants reach operating temperature.

IMPORTANT: before running the machine be sure to avoid any possible related damage.

IV. Check the operation/function/condition of the various components/systems of the machine.

V. List all unsatisfactory conditions and required corrective actions in the "**Technician report table**" (page 1). Where relevant notify your local Case IH Representative office, by submitting an ASIST Concern Report.

VI. Once completed, return a copy of the "**PDI report**" (4 pages) in the envelope that is provided. It is NOT necessary to pay for postage that has been paid for by Case IH.

HOW TO FILL THE BOXES

OK: Where the item is in a satisfactory condition insert ✔ in the OK column.

Not Applicable: If an item is NOT APPLICABLE to the specific unit under inspection, insert **NA** in the OK column.

Unsatisfactory condition: Where an unsatisfactory condition is detected and fixed, insert ✔ in the OK column, insert **X** in the X column and complete the "Technician report table" (page 1).

Technician report table (page 1): Insert the <u>item number</u>, describe the <u>unsatisfactory condition</u>, describe the <u>corrective action/repair order/claim number</u>, and insert the <u>type</u> of the problem fixed. For the PDI purpose there are 6 types of problem:

1. INOPERATIVE PART
2. OMITTED PART
3. INCORRECT PART
4. DAMAGED PART
5. INCORRECTLY FITTED/FILLED
6. CONTAMINATED

NOTES

Note 1: It is <u>unnecessary</u> to check the tightness of bolts, nuts or connections except where specifically listed. Do NOT tighten any components unless it is necessary (e.g. to rectify a fluid leak).

Note 2: The "<u>Comment column</u>" of this document is available for Dealer references.

Note 3: During the <u>Dynamometer test</u> insert the readings of the instrument in the five boxes. This information describes the performance of a new engine, therefore the readings in the section are not to be considered as items to check.

Annex 2: Literature Content Summary Analysis Elements

Author	Research Objective	Methodology	Optimization Strategies	Evaluation Metrics	Key Findings
(Amaral, 2020)	To address the Double Row Layout Problem (DRLP) by proposing a heuristic approach.	Involve different strategies for optimizing the layout of machines on two parallel rows to minimize material flow costs.	Consists of an improvement using heuristic approach to optimize a random double row layout and adjust the absolute position of each machine using Linear Programming.	1. Average Deviation (Avg dev) 2. Relative Standard Deviation (rSD) 3. Percent Deviation (dev)	1. The two-phase algorithms consistently produced high-quality solutions. 2. The two-phase algorithms significantly outperformed the LS-minFFasym method.
(James et al., 2020)	To identify and prioritize the critical challenges faced by automobile maintenance service garages.	Multi-criteria Decision-Making (MCDM) methods are employed to identify, analyze, and prioritize the challenges faced by automobile maintenance service garage.	Involves the application of Interpretive Structural Modeling (ISM) and Analytic Hierarchy Process (AHP) techniques.	1. Consistency Index (CI) 2. Consistency Ratio (CR)	1. The identification of nine challenges faced by automobile maintenance service garages in India. 2. The research provides a comprehensive framework for addressing these challenges.
(Rifai et al., 2023)	To provide a layout design for the pyrolysis	The use of ALDEP (Automated Layout	-	Total Cost of Layout (TCL) value	1. Significantly improve efficiency in facility layouts.

Author	Research Objective	Methodology	Optimization Strategies	Evaluation Metrics	Key Findings
	machine manufacturing process.	Design Program) algorithm for designing the facility layout.			2. Substantial improvements in facility layout arrangements.
(Hanum, 2021)	To implement an optimum factory layout design using CORELAP software to reduce material movement distance and handling costs in a manufacturing facility.	Involves quantitative research with primary (observation & interview) and secondary data (reports) collection methods.	Computerized Relationship Layout Planning (CORELAP) method.	1. Material movement distance 2. Handling cost 3. Overall improvement in production efficiency	1. Decrease in material handling costs by 65% in one cycle. 2. Re-arrangement of the facility layout to acquire an addition to the facility.
(Boby & Bibin, 2018)	To address the low productivity issue by optimizing the facility layout.	Layout analysis and simulation modeling and optimization of the plant layout.	1. Computerized Relationship Layout Planning (CORELAP) method. 2. Arena Simulation Software.	1. Distance between machines 2. Material movement time	1. Significant improvement in productivity by 7.98% after optimizing the plant layout 2. Reduction in material movement time between critical machines
(Mebrat et al., 2020)	Design the production layout of Gemal Rogora General	1. Gather information on flow, activity, space	1. Computerized Relationship Layout Planning (CORELAP)	1. Efficiency	1. Alternative Layout Efficiency: the alternative layout showed higher efficiency

Author	Research Objective	Methodology	Optimization Strategies	Evaluation Metrics	Key Findings
	Mechanical Workshop (GRGMW) to enhance productivity.	availability, and requirements. 2. Compare existing layout with alternative layouts to enhance productivity.	method for layout design and optimization.	2. Effectiveness material handling costs and savings between layouts: 3. Space Utilization	and cost savings compared to the existing layout. 2. Productivity Enhancement. 3. Space Utilization Improvement:
(Rudolf & Martina, 2019)	Optimizing production processes by facility layout improvement.	Involves quantitative research with primary (observation & interview) and secondary data (reports) collection methods.	CRAFT method to determine the optimal distribution of elements in the production process	1. Handling costs 2. Distances between activities 3. Material flows within the production process	Adjustments to reduce costs, optimize material flows, and improve production processes, leading to enhanced efficiency and cost-effectiveness in manufacturing activities.
(Turan et al., 2021)	Solve a multi-objective optimization problem for facility location.	Measuring average fleet availability, total cost and total inter-regional transaction.	System Dynamics simulation model and NSGA-II (Non-dominated Sorting Genetic Algorithm-II) optimization algorithm.	Fleet availability, total cost, and total inter-regional transactions.	The effects of changes in industrial manpower, dock schedules, crew recruitment rate, and alternate maintenance region preferences on the evaluation metrics.
(Zuniga et al., 2020)	Building and validating conceptual &	Using Functional Resonance Analysis	Simulation based optimization.	1. Throughput, 2. Work-in-progress	A methodology that considers production and logistics

Author	Research Objective	Methodology	Optimization Strategies	Evaluation Metrics	Key Findings
	simulation models for optimizing facility layout.	Method (FRAM) model to analyze stages in the facility layout design.	(Flexsim, PlantSim, and Facts Analyzer).	3. Lead time 4. Distance between departments 5. Buffer capacity 6. Number of transports	constraints when designing a facility layout.
(Liu et al., 2020)	To explore the feasible space of the Constrained Single-Row Facility Layout Problem (cSRFLP).	1. Formulating mixed-integer programming models for different variations of the Constrained Single-Row Facility Layout Problem (cSRFLP). 2. Utilizing the CPLEX optimization software for comparisons.	1. Mixed-integer programming models 2. CPLEX optimization software for comparison 3. Constrained improved Fireworks Algorithm (cIFWA)	1. Best, average and standard deviation values. 2. Comparison of results obtained using the constrained improved Fireworks Algorithm (cIFWA) with those from the CPLEX optimization software.	Proposed constrained improved Fireworks Algorithm (cIFWA) for solving the Constrained Single-Row Facility Layout Problem (cSRFLP) efficiently.
(Guan et al., 2019)	To minimize overall material handling costs, reduce the number of workshops required for departments, and	1. Development of a mixed-integer linear programming model. 2. A multi-objective genetic algorithm, is	1. Multi-objective genetic algorithm 2. A discrete framework for particle swarm optimization	1. Comparison of objective function value 2. Running time 3. Relative deviation criteria	The efficiency of the proposed method (MOPSO algorithm) in solving complex optimization problems.

Author	Research Objective	Methodology	Optimization Strategies	Evaluation Metrics	Key Findings
	optimize the utilization ratio of the shop floor.	utilized to optimize the problem.			
(Han et al., 2021)	To optimize a dynamic facility location-allocation problem for agricultural machinery maintenance services.	1. Formulating a Multi-Period Capacitated Facility Location Problem (MCFLP). 2. Benders decomposition algorithm is developed to analyze different facility location-allocation scenarios	Benders decomposition algorithm	1. Total service mileage 2. Reduced service mileage 3. CPU time	The Benders algorithm refinements contribute to efficient solution iterations and computing time in solving the dynamic facility location problem for agricultural machinery maintenance service.

Annex 3: Observation

1. The overall facility environment was observed.

2. Physical observation of the facility has been done.

3. The maintenance facility infrastructures have been observed.

4. The relationship between the departments of the facility has been observed (including the distance between workstations).

Annex 4: Interview Question (For Maintenance Personnel)

Education Level: ______________________

Service Year: _________________________

Gender: ______________________________

Interview Questions

1. How does the current layout of the agricultural machinery maintenance facility impact the workflow and efficiency of maintenance operations?

2. What are the key bottlenecks or areas of congestion in the existing layout that hinder the smooth flow of machinery through the facility?

3. What are the major factors contributing to the maintenance time in the current layout, and how do they impact the overall turnaround time for machinery maintenance?

4. How does the current layout affect the accessibility and availability of critical components, spare parts, and inventory for maintenance activities?

5. How does the current layout impact the coordination and communication among different maintenance teams or departments within the facility?

6. How does the existing layout design align with industry best practices and benchmarks for agricultural machinery maintenance facility?

Annex 5: Interview Question (For Management)

Education Level: ______________________

Service Year: _________________________

Gender: ______________________________

Interview Questions

1. How does the current layout of the agricultural machinery maintenance facility impact the workflow and efficiency of maintenance operations?

2. How does the current layout affect the accessibility and availability of critical components, spare parts, and inventory for maintenance activities?

3. How does the current layout impact the coordination and communication among different maintenance teams or departments within the facility?

4. What existing systems or tools are currently used for tracking equipment status, maintenance tasks, and technician activity?

5. Are there any specific challenges faced in terms of data collection, storage, and accessibility for monitoring maintenance activities?

6. From a management perspective, what features or functionalities would be most valuable in a control and monitoring system for the new layout?

7. How does the existing layout design align with industry best practices and benchmarks for agricultural machinery maintenance facility?

Annex 6: Group Discussion

No.	Discussion Points	Participants	Date
	Group Discussion – 1		
1	Maintenance facility supporting facilities	Mr. Lemma Taddesse Ms. Edelawit Hailu Mr. Siraj Awoel Mr. Gulema Assefa Mr. Tsegaye W/mariam Mr. Shegol W/hanna Mr. Dagmawi Mekonnen	April 25, 2024
2	Relationship between maintenance facility departments		April 25, 2024
3	Area and capacity for maintenance facility departments		April 25, 2024
	Group Discussion – 2		
4	Department placement of the CRAFT excel add-in output		May 18, 2024
5	Departments with frequent interaction		May 18, 2024
6	Size and capacity of departments		May 18, 2024

Annex 7: Travel Time (Distance covered per second)

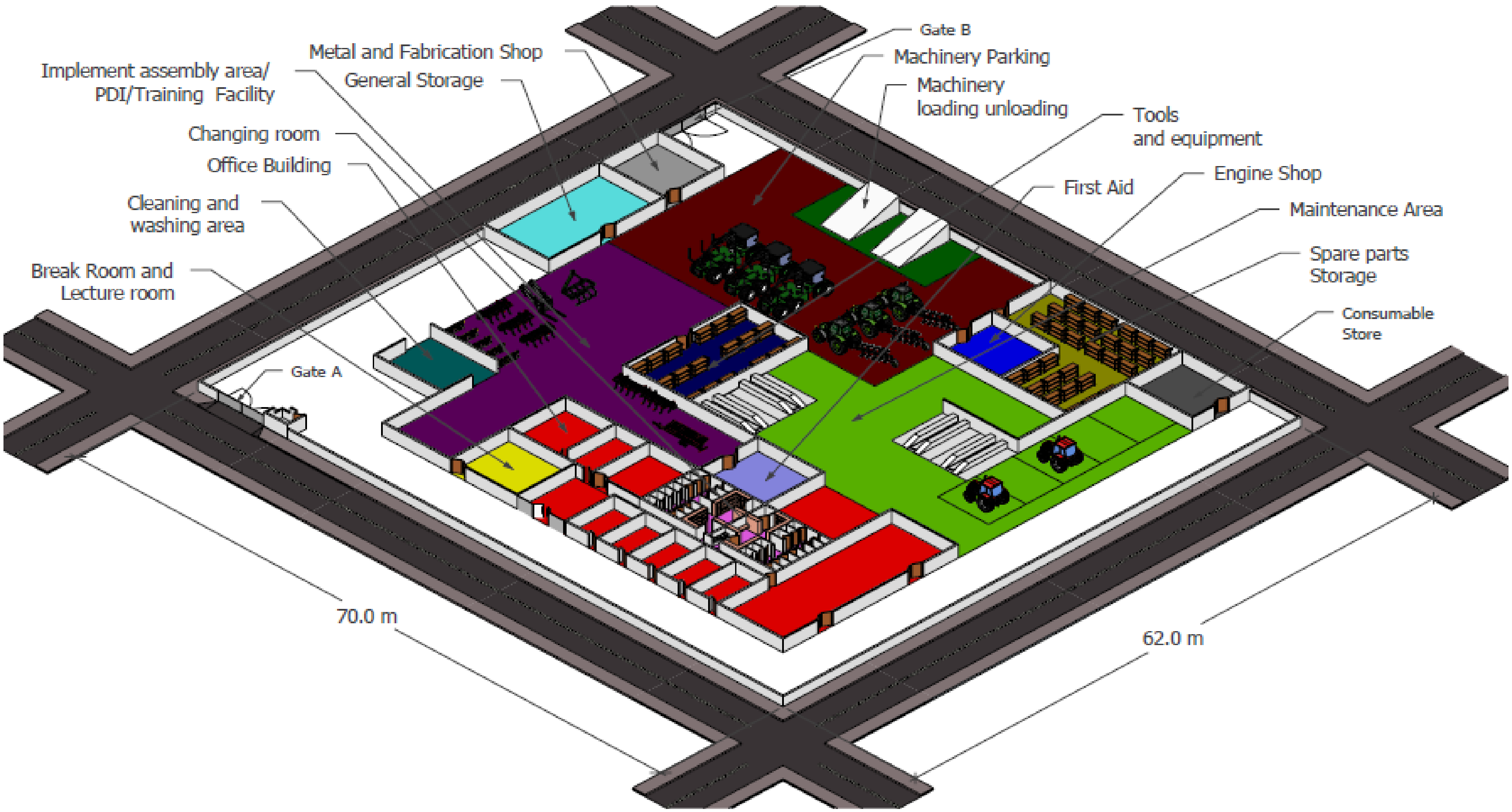
No.	**Description**		**Distance**	**Total travel time**
	From	**To**		
1	Maintenance Area	Spare Parts Storage	300 m	2m 58s
2	Maintenance Area	Parking Area	20 m	0m 16s
3	Maintenance Area	Consumables Storage	30 m	0m 24.5s
4	Maintenance Area	Implement Assembly	350 m	5m 56s
5	Spare Parts Storage	Parking Area	270 m	3m 21s
6	Spare Parts Storage	Consumables Storage	330 m	3m 49s
7	Spare Parts Storage	Implement Assembly	630 m	12m 50s
8	Parking Area	Consumables Storage	50 m	0m 45s
9	Parking Area	Implement Assembly	360 m	7m 14s
10	Consumables Storage	Implement Assembly	320 m	6m 34s
	Total Distance and Time		2,660	44m 11s
	Average distance per time (m/s)			**1.003 m/s**

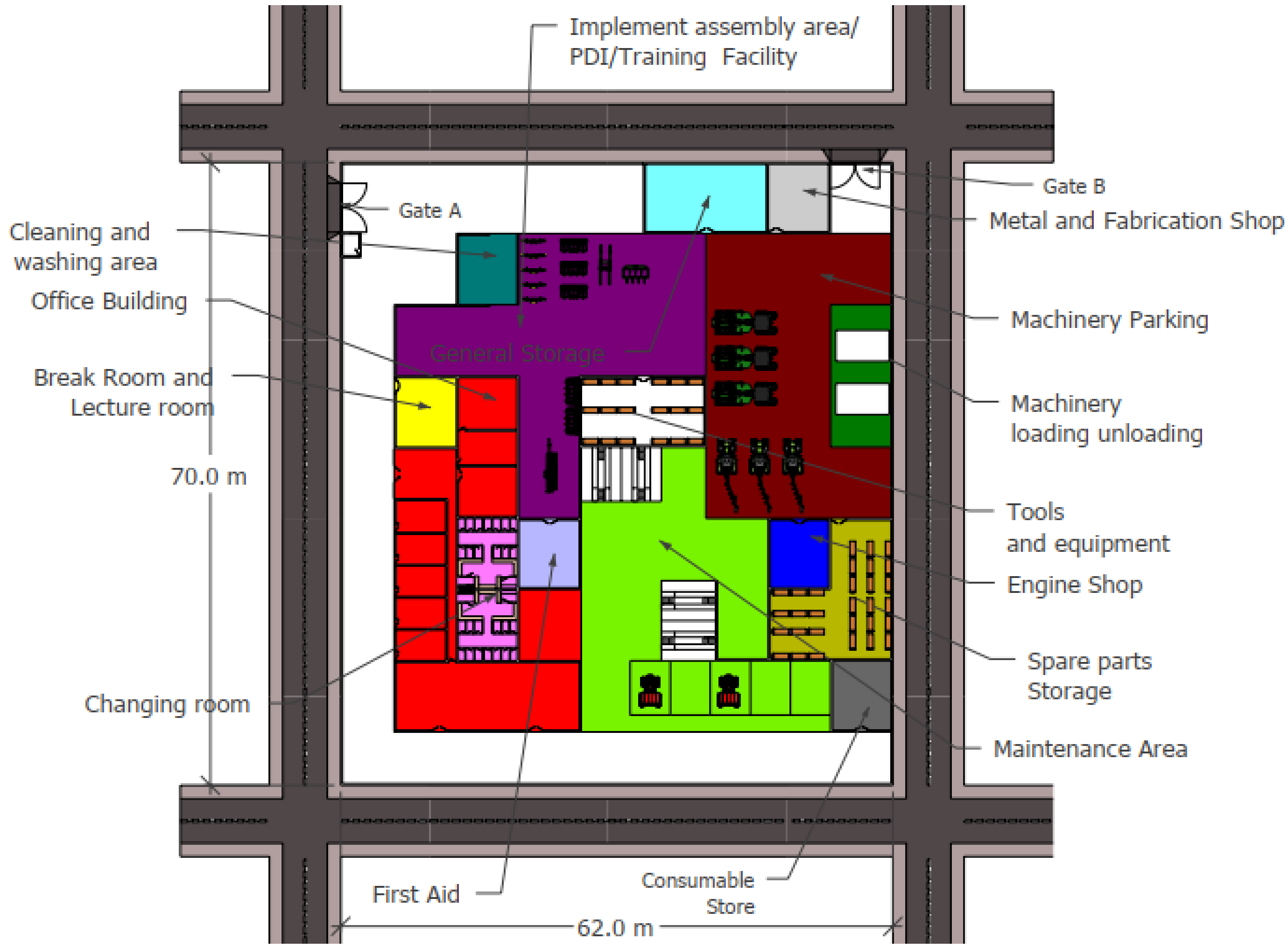
Annex 8: Time Study (in Min)

	Machinery Loading/Unloading	Theoretical Training	Practical Training	Machinery Parking
Observation	Recorded Time	Recorded Time	Recorded Time	Recorded Time
1	5.8	180	80	10080
2	6.9	210	90	14628
3	5.2	225	105	12432
4	6.4	191	93	8543
5	5.6	202	86	6226
6	5.7	228	108	16757
7	5.2	214	85	11100
8	6.6	196	76	24300
9	5.4	184	89	9870
10	6.1	201	94	40750

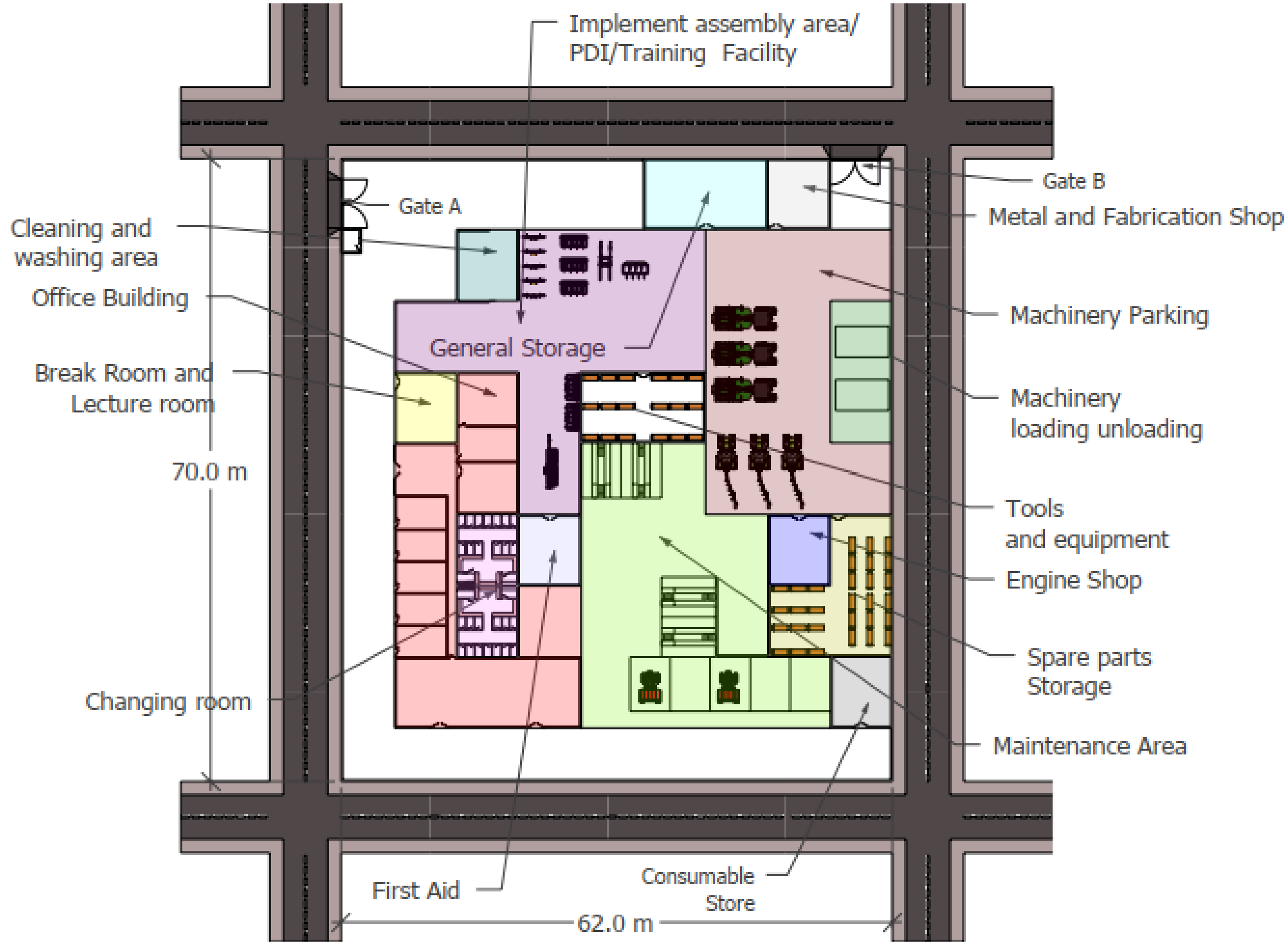
	Maintenance Service	Implement Assembly	Pre-delivery Inspection	Machinery Parking
Observation	Recorded Time	Recorded Time	Recorded Time	Recorded Time
1	8080	720	400	10080
2	8095	1440	383	14628
3	8120	1440	378	12432
4	8140	240	414	8543
5	8060	960	392	6226
6	8135	240	401	16757
7	8115	360	412	11100
8	8075	480	365	24300
9	8150	480	389	9870
10	8105	240	411	40750

Annex 9: Proposed Facility Layout





Implement assembly area/
PDI/Training Facility
Gate A
Gate B
Metal and Fabrication Shop
Cleaning and
washing area
Office Building
Break Room and
Lecture room
General Storage
Machinery Parking
Machinery
loading unloading
70.0 m
Tools
and equipment
Engine Shop
Spare parts
Storage
Changing room
Maintenance Area
First Aid
Consumable
Store
62.0 m


Implement assembly area/
PDI/Training Facility
Gate B
Gate A
Metal and Fabrication Shop
Cleaning and
washing area
Office Building
Machinery Parking
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