



**VAN GERREVINK**  
vertrouwd recyclen

# UNIVERSITY OF TWENTE.

## Facility design to improve the internal logistics at Van Gerrevink

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## Management Summary

This research is conducted at Van Gerrevink, a company specialized in handling waste flows. Activities include transferring, sorting, processing and destroying material flows like paper, metal, wood, plastics and electronics. The current location is in use since 1972 and remained the same for the ever increasing supply of materials. The steady growth of the company has its impact on the activities on the terrain. The increasing number of vehicles entering the terrain also increases the workload of the equipment and impacts the trips made for internal transportation. Vehicles experience more and more delays and congestion on the terrain, leading to safety hazards, higher risk of damages, increased operational cost and loss of customers. The original layout of the terrain was not designed for the current throughput and is not optimized for the current material flow. To determine if and where improvement can be made, we analysed the current situation and designed multiple alternative layout options. Using a simulation model, we evaluate the impact of these adapted layouts. The following main question is the base of this research:

**What is the performance of the current layout and how can this be improved in terms of cost, safety and utilization.**

In literature we found many approaches to creating and adapting facility layouts. We applied systematic layout planning for an initial green field situation, which can be used as a benchmark of how good other layouts perform. CRAFT is used to adapt an initial layout and uses swaps to identify better department arrangements. Starting from the current layout, we used CRAFT to create three alternative layouts. Combined with the analysis of the current and greenfield solution, this makes five different layout options to compare. For the comparison of the layouts we use a discrete event simulation model implemented in Tecnomatix PlantSimulation version 13.

To compare the different layouts and make the results measurable, we used the following KPIs:

- Staff utilization
- Distance driven
- Waiting time
- Number of trucks at the location at the same time
- Distance driven by each forklift
- Time spent on the terrain by a truck on each location

When comparing the results from the simulation study, we find that the current layout can be improved on multiple points. For external vehicles, we find that relocating the weighbridge has a significant impact on waiting times and driven distances. For waiting times, we find an average reduction of 55%. The driven distances can be reduced up to 26% for external vehicles. It also reduces the number of trucks at the location at the same time and the time a vehicle has to spend on the terrain. When looking at internal transportation, we consider the transportation of paper. The best way to improve the KPIs for the internal transportation vehicles is to place the locations that handle the same material closer together. In the current situation, vehicles cover large distances to transport materials back and forth. For the included forklifts we found possible improvements up to a reduction of 33% in driven distance. Placing the bale storage locations between the baler and the loading area would eliminate driving time.

## Acknowledgements

I am proud to present the final piece of work that completes my master Industrial Engineering and Management at the University of Twente. What a journey it has been! After the first few weeks, working from home became the new normal due to the corona outbreak, which has its pros and cons. I would like to take a moment to show my gratitude to all involved during this process to make it happen.

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Contents

Document Information..... i

Management Summary.....ii

Acknowledgements .....iii

1. Introduction..... 1

    1.1 Company background..... 1

    1.2 Research motivation..... 1

    1.3 Problem description ..... 2

    1.4 Research objectives..... 3

    1.5 Research questions..... 3

    1.6 Problem approach ..... 5

    1.7 Deliverables ..... 7

2. Literature Review ..... 9

    2.1 Facility layout design ..... 9

    2.2 Facility layout optimization ..... 12

    2.3 Facility layout evaluation..... 17

    2.4 Conclusions..... 21

3. Current situation ..... 22

    3.1 Facility layout..... 22

    3.2 Data collection and analysis ..... 29

    3.3 Key performance indicators ..... 43

    3.4 Conclusion ..... 43

4. Defining new layout options ..... 44

    4.1 Choice of approach..... 44

    4.2 Creation of the greenfield solution ..... 45

    4.3 Improved layout plans..... 48

    4.4 Craft result comparison..... 51

    4.5 Conclusion ..... 51

5. Simulation model ..... 52

    5.1 Conceptual model ..... 52

    5.2 Simulation model ..... 59

    5.3 Verification and validation ..... 59

    5.4 Conclusions..... 60

6. Determination of layout performance using simulation..... 61

    6.1 Waiting times ..... 61

    6.2 Utilization of locations and roads..... 63

    6.3 Driven distances ..... 63

    6.4 Average number of vehicles present at the same time ..... 64

6.5	Forklift utilization .....	64
6.6	Conclusions.....	65
7.	Conclusions and recommendations .....	67
7.1	Conclusions.....	67
7.2	Discussion .....	67
7.3	Limitations .....	68
7.4	Recommendations.....	68
8.	References.....	69
A.	Company certifications.....	73
B.	Mathematical modelling definitions .....	74
C.	Data tables.....	75
D.	Overview of distributions and determination of simulation parameters .....	77
D.1	Arrival distributions .....	77
D.2	Determination of the weight distributions: .....	78
E.	Number of replications.....	88
F.	CRAFT results.....	89
F.1	Current layout CRAFT .....	90
F.2	Current layout with weighbridge moved CRAFT .....	92
F.3	Greenfield CRAFT.....	94
F.4	Layout option 1 CRAFT .....	96
F.5	Layout option 2 CRAFT .....	98
F.6	Equal size departments width 5 .....	100
F.7	Equal size departments width 7 .....	102
F.8	Equal size departments width 14.....	104
G.	Simulation results for vehicles .....	106
G.1	Current situation .....	106
G.2	Current layout with weighbridge moved .....	106
G.3	Greenfield layout.....	107
G.4	Layout option 1.....	108
G.5	Layout option 2.....	109

# 1. Introduction

This chapter introduces the research performed at Van Gerrevink to complete this master's thesis for the study Industrial Engineering and Management. Section 1.1 provides information about the company and gives a short summary of its history, mission, and vision for the future. In Section 1.2 we explain the motivation for this research, followed by the problem description stated in Section 1.3. We formulated the research objectives Section 1.4. In Section 1.5, we state the different research questions. Section 1.6 provides information on our problem approach and how we aim to complete the project. The final part, Section 1.7, provides the deliverables of this research project.

## 1.1 Company background

The history of Van Gerrevink can be traced back to 1685 when the family began producing paper. During the next centuries the family ran businesses in multiple disciplines at different locations. Van Gerrevink B.V. specializes in professional recycling and destruction. Services are offered to individuals, companies and governments since 1879. The company began working from their current location at Sint Maarten 2 in Apeldoorn in 1972. Activities consist of transferring, processing, destroying and sorting, among other things, paper, metal, wood, plastic and electronic waste. The company processes these materials against multiple certifications, which are provided in Appendix A. Currently the board is formed by Marc van Gerrevink, the fifth generation of Van Gerrevink, and Adriaan de Putter (Van Gerrevink BV, 2020). Van Gerrevink has five main departments: commerce, production, planning and logistics, administration, and supporting services.

### 1.1.1 Company mission

The company mission is "From waste to raw materials in a professional way". Van Gerrevink aims to assist their relations in a professional, modern and personal way to unburden them from their waste, destruction of confidential documents and goods, and to deliver high-quality secondary materials (Van Gerrevink BV, 2019).

### 1.1.2 Company vision

The vision of the company is to be a professional and regionally strong player in the recycling business. By widening its scope to be a total caretaker in the field of waste and using their years of experience in the recycling world, the aim is to reduce the ecological footprint of the company and its relations. Personal contact between staff members and company contacts is one of the core values of the company.

## 1.2 Research motivation

The current location of Van Gerrevink processed over 65,000 tonnes of different kinds of waste in 2019. To supply all this waste and dispose of raw materials, over 26,000 vehicle movements were registered in 2019. There is also internal transportation necessary, which is done by forklifts, cranes and a wheel loader. Since the work at the current location began in 1972, the company kept growing but the available location size remained the same. The original building is not optimal for the modern trucks and forklifts because of its height limitations. Over time, more sheds and warehouses were built but this did not have a sufficiently positive effect on internal logistics. The current management expects the two hectares of terrain to be sufficient for the operations of Van Gerrevink, but the large spread of material flows and storage locations results in a large number of internal movements. The vast amount of internal movements incurs cost and results in safety hazards. The current machinery consists of a number of static machines with weights exceeding 40 metric tonnes, which are hard to move and expensive to relocate. The company wishes to increase the efficiency and effectiveness of its internal logistics; for this, multiple layout adaptations can be thought of. Given the nature of the machinery and layout of the current facility, high building and relocating cost can be incurred. It is important that the effects of redesigning the facility are thoroughly studied.

### 1.3 Problem description

The growth of the company over the years increased throughput and created the need for more indoor working space. These spaces were constructed next to the existing ones and on another part of the terrain. The increase in production and working locations eventually led to many vehicles moving goods and entering the terrain for loading and unloading. When a location is in use by a vehicle it is not always accessible to others, which leads to vehicles waiting and sometimes to rerouting of the vehicle. When a vehicle is rerouted to another location, it means that the load has to be moved again to the right location at another point in time, increasing movement on the terrain and thus increasing cost and workload. Incoming and outgoing vehicles are registered, which gives a clue about the flow of materials on the yard. There is limited understanding of the current flow of materials on the site, since exact movements are not recorded.

To create an overview and clear understanding of the problem(s), the method known as a problem cluster is used. A problem cluster is used to show multiple problems with their mutual relations (Heerkens & Winden, 2012). Figure 1-1 presents our problem cluster to help determine the problems behind the experienced issues. The flow in our problem cluster goes from cause (green) to consequence (red).

The core problem is identified using the following four rules of thumb (Heerkens & Winden, 2012):

1. Only problems of which we are sure that they occur are in the problem cluster, this is to prevent solving non-existing problems.
2. Look for a problem that does not have a cause, this can be a possible core problem.
3. Things that cannot be influenced cannot be a core problem. A core problem should always be solvable.
4. Choose, in case of multiple problems, the most important one to solve. This will be the problem that will have the biggest effect when solved.

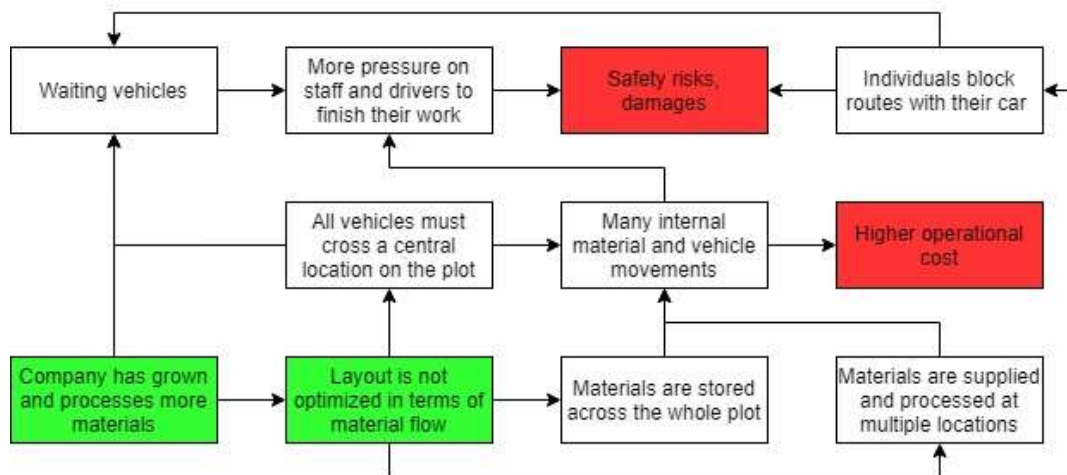


Figure 1-1 Problem cluster

The problem cluster in Figure 1-1 shows the connections between our visible problems and the underlying causes. The red boxes are the eventual results of the problems that originate from the points in the green boxes. The growth of the company can be seen as the main issue resulting in the listed problems. The growing amount of vehicles and materials that have to be processed make that the layout that was once adequate enough to handle all movements, starts to show its weakness. The current layout is not optimized in terms of material and vehicle flows. Vehicles must all cross a central point on the terrain twice per visit. Materials are stored at multiple locations on the terrain, which incurs large driving distances for internal transportation. At the end of the diagram, we find the problems resulting from the main causes. The most important visible symptoms are that vehicles are

waiting, staff experiences high working pressure, and the large amount of internal movements that occur. A solution would be to reduce the workload and thus movements and waiting times; this is however not desirable since it has a negative impact on the business of the company. By optimizing the layout of the terrain, the aim is to reduce the amount of internal material movements, vehicle crossings at a central location, and the large spread of storage- and supply points. We expect to see improvements in terms of less waiting time, less safety risks and damages, less time pressure for personnel and a reduction in operational cost.

#### 1.4 Research objectives

The company is looking at the possibilities to rearrange the layout of the location, but the amount of time and money invested in such a plan must be justified. Van Gerrevink wants to address the problems with the internal logistics to increase their efficiency and effectiveness. The improvement of the internal logistics will most likely have a positive influence on safety, employee workload, service times for internal and external parties and operational costs. This study focusses on the creation and analysis of new layout options. Multiple layouts are analysed and compared to be able to give a final verdict about the best way to improve the current internal logistics.

A literature study is performed to find out how companies and factories can be rearranged to improve the internal flow of materials. This research looks deeper into the different layout options and their characteristics. For this it must be known in which ways the terrain can be rearranged and what the results of this will be. Furthermore, the different layout proposals must be analysed on multiple levels. First, the characteristics of the layout, like expected travel times, waiting times and incurred cost will be investigated. Next, the cost and benefits of changes must be evaluated. Using this combination of characteristics, the different layouts can be compared. Conclusions can be drawn and recommendations can be made based on this comparison.

#### 1.5 Research questions

In this section, the research question and sub questions used for this project are discussed. Sub questions are used to build knowledge or gain insight in current processes and give structure to the report. In order to structure the answering of the sub-questions, sub-sub-questions are used.

The main research question is defined as follows:

**What is the performance of the current layout and how can this be improved in terms of cost, safety and utilization?**

- **What does literature say about facility layout design, layout optimization and evaluation of layout performance?**
  - Which kind of layout problems and options are known in literature?
  - Which modelling options are applicable to the problem?
  - Which methods are used to evaluate facility layouts?
  - Which methods for layout planning are used in literature?
  - What is the best methodology to create a new layout design?
  - Which methods for layout improvement are used in literature?

The goal of this question is to identify possible solution approaches for the problem at Van Gerrevink. To accomplish this, it is important to know which kind of problems, methods and techniques there are and which can be applied. First, the different kind of layout problems are discussed, so the situation at Van Gerrevink can be classified. Next, different modelling techniques are investigated to identify a method that is applicable to the problem and can deliver the desired output. Different methods used to evaluate facility layouts discussed in literature will be compared. The modelling techniques and evaluation methods are compared and the ones that are expected to yield the best results to answer the main question will be selected. The final step to answer this question is to find out which methods are used to plan and improve layouts. Layout planning is deciding on the best physical arrangement of

all resources that consume space within a facility (Reid & Sanders, 2011). From these methods the best way to setup a new layout and improve the current layout can be derived.

- **What is the current situation at the location of Van Gerrevink?**
  - Which key performance indicators (KPIs) are important and can be used in the evaluation?
  - Which material flows are present and how important are they?
  - What data is available?
  - What data can be acquired?
  - What are the requirements for each of the departments?

This question is devised to gain insight in the current situation at the yard. Information about the current processes and situation is key to be able to make improvements. Therefore available data is processed and other required data is identified. The first steps are important for identifying bottlenecks on the terrain and in the processes. Finally, the important requirements for the departments are listed, e.g., some departments may require to be located indoors, while for others it does not matter.

- **How can new layouts for Van Gerrevink be created?**
  - Which methods are best suitable to create and adapt a layout for this location?
  - What is the best methodology to adapt the current layout?
  - What are the best changes to apply and what does the new situation look like?
  - Where can improvements be expected?
  - How much improvement can be expected?

This question is an important step to answer the main research question. Methods for layout creation and adaptation are selected and applied. During this process multiple layouts are evaluated and the best are selected for further analysis.

- **How can a simulation model be designed to evaluate the different layouts and what performance can be expected from these layouts?**
  - What does the simulation model look like?
  - What input is needed for the simulation model?
  - What are the characteristics of the simulation model?
  - What are the results from the simulation models of the different layouts?

Based on the KPIs determined in the description of the current situation, the layouts can be evaluated. To answer this question all layouts are evaluated using a simulation model, to determine the values for the KPIs. When the performances of the individual layouts are determined they can be compared to one another. The comparison shows the effects of choices made in the layout planning process. With this comparison it can be made clear where benefits lie for Van Gerrevink on the improvement of the internal logistics.

## 1.6 Problem approach

In this section the approach to tackle the problem is discussed. We subsequently discuss the formulation of the approach, research methodology, data acquisition and validation, report structure and project scope and the deliverables of the project.

### 1.6.1 Formulating the approach

Kothari (2004) describes two basic approaches to research: the qualitative approach and the quantitative approach. The qualitative approach is concerned with the subjective assessment of attitudes, opinions and behaviour; it involves collecting and analysing non-numerical data. A quantitative approach involves the generation of data in quantitative form, which can be subjected to quantitative analysis in a formal and rigid manner. The quantitative approach can be divided into inferential, experimental and simulation approaches. The simulation approach involves the construction of an artificial environment within which relevant information and data can be generated. This way the dynamic behaviour of a system can be observed. Law (2015) describes different ways to study a system with the use of a diagram (see Figure 1-2).

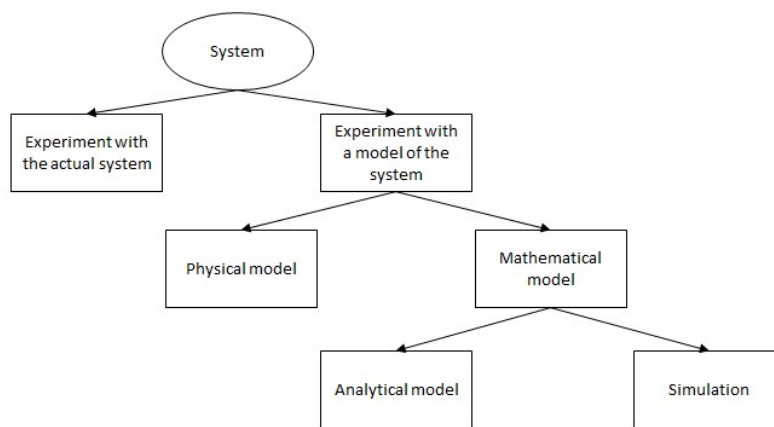


Figure 1-2 Ways to study a system (Law, 2015)

Experimenting with the system is key to determine the results of changes. Some experimentation can be performed with the actual system, like making people use fixed routes or limiting the number of vehicles that can enter the terrain at the same time. Most of the changes we would like to evaluate are harder to implement in the actual system. Given the incurred cost and downtime, we cannot move main departments every other day to see what works best, which leads us to experimenting with a model of the system. This experimenting can be done using a physical or a mathematical model. Mathematical models represent a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts, and thus how the actual system would react (Law, 2015). Given the dynamic nature of the processes on the yard, an analytical model cannot be used to give a final answer. The complexity and dynamic nature of the system can be modelled in a simulation. This means that the system is studied by running the model for different inputs to see how the output of the model is affected.

Qualitative methods have been previously applied by the company. The company has asked its employees to draw the departments on a blank outline of the yard, results from this will be discussed in Section 3.1.1. These drawings are all based on employee ideas and not numerically supported, but they can give insight in the ideas of the people who run into problems with the company layout. For this research, a quantitative simulation approach is the best fitting method. In order to evaluate the proposed layouts, a quantitative study will be applied. Since we want to evaluate the performance of a system that is not currently existing and experimenting with the layout in real-life is not feasible, the use of simulation techniques is preferred. The simulation method and techniques are explained later on in Chapter 2.

### 1.6.2 Overall research methodology

In order to structure the research, relevant methods are investigated. A literature study is performed to gain insight in currently known and applied methods that can aid in solving the problem. In order to gain insight into the current situation, a mixture of data acquisition, data analysis and data generation will be applied. Current processes will be observed and registered. Literature is used to create a knowledge base on facility layout and performance evaluation. By means of a literature study, the relevant knowledge is structured and discussed. It is also key to gather information about the business and the current situation. Information about the processes is gathered by talking to the people involved, observing the processes and some desk research. The available data from the company must be analysed and transformed to the occurring needs.

In this report we make use of applied research, which aims to find a solution for the problems defined in Section 1.3. Applied research aims at finding a solution for an immediate problem facing a society, or an industrial/business organisation. Four types of applied research are: reporting research, descriptive research, explanatory research and predictive research (Donald R. Cooper, 2014). The first part of the research will have characteristics of a reporting study, data about the current situation must be collected. From this data the connection between departments can be derived. The next part of the study, the literature study, is used to describe methods used for the adaptation of layouts and how they are to be applied at the situation at Van Gerrevink. In the final part of the research a prediction about the performance of layouts is made using simulation techniques. This last part of the study can be seen as a predictive study, where the effects of changes are evaluated.

### 1.6.3 Data acquisition

A lot of data about the movements of goods processed by the company can be retrieved from the weighbridge records and the company statistics on purchases and sales, which are registered using NewTon and AFAS. From the weighbridge-database, a lot of information about incoming and outgoing movements and materials can be retrieved. The company statistics database gives a more detailed overview of all materials and the incoming and outgoing amounts of each material type. In the remainder of this report, we assume that the amount of material flow is fairly constant and not subjected to large changes over time. There are seasonal fluctuations in demand, which we tackle by using the peak load for evaluation purposes. Sizes of departments are determined based on building plans and drawings, data is verified at the location.

GPS tracking is used to gather data on the movements of forklifts on the terrain, this data is used to find common routes and locations of the forklifts. Furthermore, data for some of the storage locations can be gathered by investigating the camera surveillance footage. Reviewing the footage can provide insight in the movements and times spent on the terrain. The data from the footage and the weighbridge can be compared and matched to each other to validate timestamps. The records from the surveillance cameras can be used to count how many individuals enter the terrain on a given day, and monitor how long their visit lasts. The location where they go can also be found on the footage. Furthermore, a camera monitoring the small paper dumping place can be used to quickly count the number of vehicles visiting that location and how long that visit takes. Data can also be collected by means of counting and timing movements on the terrain.

### 1.6.4 Data validation

We assume that the data from the weighbridge database is correct; it is directly connected to all material management and financial processes. The data from the weighbridge can be used to construct distributions for expected arrival times, types of vehicles, weights, etc. It is important that these distributions are validated. This can be done by keeping small parts of data separate and comparing the data to the distributions. The datafiles can also be compared with data gathered in real live using observations, the gathered values should be in-line with the values from the database. Enough data must be available to show that the results are statistically significant.

Data gathered by GPS-tracking can be verified by monitoring the movements of a tracked vehicle in real live for a period of time and comparing this with the data received from the GPS-system. The accuracy and behaviour of the system when it is not moving determine greatly how valuable this information is. Tracker data will most likely need filtering on invalid data points.

### Report structure

First, the introduction is used to provide information about the company, the problem and the research. The research questions defined in Section 1.5 provide a backbone to the structure of the report. The sub-questions that are used to answer the main question are detailed in their own chapters. After the introduction, a literature study is performed and relevant literature is discussed in Chapter 2. The literature study is used to gain insight in current methods and knowledge and to get ideas about relevant information to gather. After the literature study, a description of the current situation is given in Chapter 3. The current situation is described in terms of available data, material flows, business processes, performance, etc. In Chapter 4 we elaborate on the creation of a new greenfield layout and adapted layout options. Chapter 5 is used to provide the details of the simulation study. First, the conceptual model is discussed, which includes the goal, assumptions, simplifications, inputs, outputs, the occurring simulation events, and simulation characteristics. Next, the implementation of the simulation model is shown. Multiple models are generated, each specified for the designed layout. Verification and validation are subsequently discussed. Chapter 6 shows the results of layout evaluation. In this chapter the results from the simulation model are compared and discussed. The final conclusions and recommendations are discussed in Chapter 7.

### 1.6.5 Research scope

This research does not consider the location of the yard, only the location of the departments on the yard. The research focusses on the higher level layout and will not focus on smaller details. Exact layouts of the departments itself are not considered. For example, the layout of utilities for staff like the breakroom and toilets are not considered. Material flows are used based on main material flows or processing method, e.g., eighty types of paper can be distinguished but we only look at the material paper and the corresponding processes. For the analysis of flows, only vehicle and material movements are considered.

## 1.7 Deliverables

The deliverables of this project include:

- A theoretical background on the improvement and evaluations of facilities.

The theoretical background will help guide the design of the layouts. By making use of existing proven theories and methods a good result for the company is more likely. The evaluation of multiple methods can also show that a good method is applied and allows to construct a framework that can be used to find a suitable layout.

- A framework that can be used to find a suitable layout.

This framework can be used to construct the different layouts. By creating a guideline based on found theory, the steps and choices taken are clear and can be retraced in case changes are desired.

- Proposals to improve the current layout.
  - A green field solution, a layout with no ties to the current layout
  - A low-impact solution, no movement of large equipment or buildings
  - A high-impact solution, which may include the movement of large machinery and buildings

In this report, we propose three alternative layouts based on the current layout. First, a green field solution is devised. This means that a layout is created without knowledge and restrictions from the current layout. This layout can be seen as the ideal and is used to benchmark the other layouts. Next,

a low-impact solution is created. For this situation we assume that only easy to apply measures are taken. This can be for instance moving the storage location of paper bales or relocating departments with small or no equipment. Departments that are hard to move because of large equipment or fixed infrastructure are fixed during this adaptation. The third proposal will be of an adaptation with larger impact on the company. Departments that are harder to relocate will also be considered.

- Analysis of the layouts based on KPIs

The created layouts must be analysed to show the relevance of the adaptation. Based on selected KPIs, the different layouts can be analysed and compared to each other.

- A simulation model that is able to evaluate the layouts.

A simulation model is provided that is used to test the proposed layouts and evaluate alternative scenarios. This model can provide detailed information about KPIs and strengthen the choice for the best alternative.

- A final recommendation on the best next step to improve the internal logistics.

Based on the creation and analysis of multiple layout options, a final recommendation for the company is made. This recommendation includes the best layout option for the current situation at Van Gerrevink.

## 2. Literature Review

In this chapter, relevant literature to answer the question, “What does literature say about facility layout design, optimization and evaluation of performance” is discussed. The study is divided into three parts. The first part, Section 2.1, is focussed on facility layout design. In Section 2.2, the optimization of existing layouts is elaborated on. Section 2.3 is aimed at increasing knowledge on the evaluation of facility layouts. Conclusions from the literature study are given in Section 2.4.

### 2.1 Facility layout design

Facility layout design focusses on the placement of departments within the available location. Since the location of Van Gerrevink is already known we do not focus on facility location, if the company keeps expanding it might be beneficial to look into facility location methods to find options for further expansion of physical space and the relocation of departments to another location. The information in this section provides an answer to the question, “Which kind of layout problems and options are known in literature?”. First, a description of the facility layout problem is given, followed by a description of layout problems and layout types. Next, the difference between block layout planning and a detailed layout planning is discussed. Furthermore, a study conducted at Swedish recycling centres provides some useful insights in material handling and flow structures. Finally, the conclusions about facility layout design are given.

#### 2.1.1 Layout problems

To understand and correctly classify the problems arising at Van Gerrevink, different types of layout problems are reviewed. A layout is the plan of how different departments and structures are set out on the available space. In a manufacturing system the term “departments” includes machines, work-stations, inspection stations, washing stations, locker rooms, rest areas, and other such support facilities (Heragu, 2006). In a service system, departments include offices, lounges, rest rooms and cafeteria. Physical arrangement is the assignment of the departments to specific locations on the floor. A physical arrangement of departments that minimizes the movement of personnel and material between departments, and thereby decreases material handling cost, increases a system’s efficiency and productivity (Heragu, 2006). Heragu (2006) defined four kinds of facility layout problems; service systems, manufacturing, warehousing and non-traditional layout problems.

The first discussed layout is the service systems layout problem, which covers layouts of for example insurance offices, runways at an airport, and restaurants. In order for a layout to be developed, information like number of departments, space requirements, interaction between departments and special restrictions must be known. In the case of a service system layout, aesthetics must be considered since there is a more direct customer contact in these systems.

The major considerations for the manufacturing layout problem comprise minimizing material-handling costs and providing a safe working environment for employees. Manufacturing system layout problems involve determining the location of machines, work-stations, and other departments to achieve minimal transportation cost, facilitate traffic flow and minimize risk of injury and damage.

Warehouse layout problems arise when goods need to be stores for any given length of time. A good warehouse layout should use available space effectively in order to minimize handling and storage cost. Important factors in warehouse design are shape and size of isles, height of the warehouse, location and orientation of the docking area, types of racks to be used for storage, and the level of automation involved in storage and retrieval of goods.

The fourth layout problem defined by Heragu (2006) is the non-traditional layout problem. There are many other situations than described before. The layout of a keyboard to improve ergonomics for example, or the placement of thousands of semi-conductors on a computer chip which all have to be connected. Another class of layout problems are the so-called linear placement problems or the one-dimensional space allocation problem, which involves determining an optimal linear ordering of

entities to minimize the total traffic cost between each pair of entities. Arranging books on a shelf, assigning aircraft to gates in an airport and U, L, straight line or loop layouts of machines within a manufacturing cell are all examples of the linear placement problem.

Drira et al. (2007) discuss about static versus dynamic layout problems. Most layout formulations are related to static layout problems. Static layout formulations are designed with the intention that the data about what is to be produced remains stable over a longer period of time. Dynamic layout problems on the other hand take into account possible changes in the material handling flow over multiple periods.

The facility layout problem (FLP) is the organization of efficient arrangement of interrelated facilities (departments, machines) on a manufacturing floor in order to satisfy the objectives of the firm (Aiello, Scalia, & Enea, 2013). FLP deals with the placement of facilities (departments, machines) in order to minimize the operation costs and maximize the system utilization (Aiello, Scalia, & Enea, 2012). It is beneficial to position facilities with the most interactions next to each other so as to minimize material handling time, waiting time in queue, processing time, and to maximize throughput and machine utilization (Altuntas & Selim, 2012). The simple FLP model is called the Static Facility Layout Problem (SFLP), which deals with the arrangement of same-sized facilities with a constant flow between them. The problem was first modelled as a quadratic assignment problem by Koopmans & Beckman (1957) (Sagnak, Ada, & Kazancoglu, 2018). Facility layout problems are NP-hard, which means it is nearly impossible to find an exact solution within a reasonable computation time (Amaral, 2013); to provide a solution in reasonable time, heuristics are used. Lee & Lee (2002) report that the facility layout problem consists in arranging an unequal-area facilities of different sizes within a given total space, which can be bounded to the length or width of the site area in a way to minimize the total material handling cost and slack area cost. For the situation at van Gerrevink, the standard static facility layout problem is not applicable since it only deals with same-sized facilities with a constant flow. Other more complicated methods can aid with the design of more complicated situations. Section 2.2 elaborates on multiple techniques and solutions for the adaptation of layouts.

The activities at Van Gerrevink can be seen as a mixture between service and manufacturing. Service is provided towards customers in the office and on the terrain. The other part can be seen as a manufacturing system, where raw materials are brought in and processed. Next to the service and manufacturing activities, there are also storage activities. Items like containers, paper bales and processed metals are stored until they are sold or rented, which resembles a warehouse layout problem. It is important for the company to prevent loose flying materials and emissions to comply with environmental legislations and minimize nuisance. For this, processing residual waste in a shielded environment, and making sure flooring is easy to clean are all important aspects. Care must be taken that the interests of all departments are represented and combined into a complete layout satisfying all demands.

### 2.1.2 Production layout types

In literature multiple production layout types are defined (De Productie Lay-out, 2020) (Hasan, Sarkis, & Sankar, 2011). The facility of Van Gerrevink can be seen as a production facility where incoming materials are processed to a new form. Examples of this include the pressing of paper to bales and the cutting of large metals to smaller parts. More labour is needed for the processing of incoming electronics, which are disassembled, and the cutting of paper rolls by a reel splitter. Five different flow types are discussed, each with their own characteristics.

#### *Continuous flow*

A continuous flow has products moving through a production line, with minimal standstill between operations. Continuous means large quantities of products have to be produced, while no individual pieces are to be distinguished, like fluids. Examples of this are the production of chemicals and the refining of oil.

### *One-piece Flow*

In the one-piece flow facility, products move individually among different processes with minimal waiting times in-between. Changeover between products can be realised quickly, so multiple products can be produced on one production line. An example of this is the car-industry, where cars with customer specific configurations are produced.

### *Batch Flow*

Batch-flow means that products are produced in clusters of the same type. This production method is favoured when setup between different products takes a relatively long time. A good example of this working method is the production of plastic parts with an injection moulding machine, where the changeover of dies can take a long time.

### *Job-shop*

The job-shop structure is interesting when there is no fixed order of processes or when the number of processes differs between products. This layout allows for multiple types of products to be made individually without following the same production process. Because the processes are not physically connected, the process times can differ between product types without directly influencing stockpiles. Another benefit of this layout is that products can move through production without waiting on each other, when the process can be done at multiple locations. Product examples are custom wooden window frames and doors. Products can have different sizes, require different operations, and have differing process times. Due to the functional division of departments, products can be processed independently.

### *Dock-shop*

The final layout, the dock-shop, is designed for products that are too large to move or for which the cycle times are so large that it is easier or more efficient to move the necessary materials and workers to the product. A great example of this is the construction of a ship in a dock, where each ship is custom built and workers go to the project with their materials.

### *Conclusion*

From the five different layout types, not all are applicable. The continuous flow and dock-shop layout are not relevant for the processes at the yard. One-piece flow is also less applicable, but can be applicable to the service of customers, which are helped when they arrive at the station they need to be. The complete layout can be seen as a job-shop, where different materials follow different routes along the yard. The processing of most materials can be seen as a batch-processing. Paper is pressed when there is enough to run the crane and the press, not when a single sheet of paper arrives. The metal cutter is used when there is a good amount of metal to be processed and not when there is only one piece to cut.

### 2.1.3 Block layout planning versus detailed layout planning

In literature, a distinction is made between block layout planning and detailed layout planning. Block layout planning shows relative locations and sizes of the departments, where detailed layout shows the exact locations of all the equipment, workstations, and storage within the departments. Since the scope of this research is focussed on creating a layout of all departments, we elaborate further on block layout planning. Block layout planning is a problem of significant complexity that has motivated numerous studies aimed at the development of exact and heuristic solution procedures (Malmborg, 2013). Common objectives are: expected materials handling cost, material flow volume distance, activity relationship scoring and various combinations of these. Typically, the block layout step establishes the location and perimeters of the major work centres in a facility and is followed by a detailed layout planning procedure for the departments. Block layout planning is used in many of the found algorithms and can be seen as the base method behind them. This method defines the department to be blocks of sometimes different sizes that have to be located in an optimal way. Block layout planning is a suitable method to apply at the problem of the company.

#### 2.1.4 Related work

Sundin, Björkman, Eklund, Eklund, & Engkvist (2011) identify and describe the main flows and layout types at Swedish recycling centres. The aim was also to adapt and apply production theory for designing and managing recycling centre operations. Problems such as queues of visitors, overloading of material and improper sorting occurred. The problem of visitors queueing is also applicable at Van Gerrevink and the solution found in the paper might aid the problem in this research. Sundin et al. (2011) show that in order to decrease the problems, the recycling centres should be designed and managed according to lean production principles, i.e., through choosing more suitable layout choices with visible linear flows, providing better information to visitors and providing suitable technical equipment. Improvements can be made through proper planning of layout and control of the flow of vehicles. This results in increased efficiency and capacity, shorter visits and cleaner waste fractions. Sundin et al. (2011) also point out the principal differences between recycling centres and an ordinary industrial production system. It is the function of the recycling centres to receive and take care of visitors' waste, i.e. "a push system", while industrial production systems normally order the incoming material from their suppliers, i.e. "a pull system". This same situation holds for the situation of Van Gerrevink, vehicles come to the yard to discard their materials and "push" it into the system. This system can be seen as a combination of a service (discarding waste for the client) and a production operation (paper bales, cut iron, etc.).

#### 2.1.5 Conclusion

The layout problem at Van Gerrevink can mainly be seen as a manufacturing layout problem. These type of problems focus on minimal material handling and safety. Currently material handling is one of the main tasks of employees. A lot of time is spent moving materials to the right place. Another problem arising is the storage of paper bales. One of the core businesses of Van Gerrevink is the processing of collected paper into bales. Bales are produced by the balers and stored on the yard until they are shipped. The storage area is quite large and spread across the terrain. By improving storage methods, storing and retrieving of goods can be done more efficiently. Comparing the situation to the different production layout types, we find it best fitting in the category of a job-shop structure, where there is no fixed order of processes for materials entering the system. Individual departments and processes can be seen as having batch flow, or even one-piece flow applications. A new layout plan can best be created using methods based on block layout planning. From the work of Sundin et al. (2011) we can learn that it is important for visitors to know where they have to be in order to improve throughput. This can be improved by instructing people before they enter the terrain and the use of clear signs. It is also clear that the inflow of vehicles to a recycling station is hard to control since most goods are not brought in following a schedule, but when there is enough material to make the trip. This is also applicable to the situation of Van Gerrevink, only rough pickup appointments can be made. Furthermore, crossing traffic should be kept to a minimum to avoid congestion and increase safety.

## 2.2 Facility layout optimization

In this section we discuss the creation of new facility layout plans and the redesign of existing plans. Starting with a review aimed at the creation of new facility layout plans, which includes a framework to guide the process and multiple techniques that can be applied. The second part of the section is aimed at the redesign of existing layout plans, the structure is the same as in the first part, but with the focus on redesign instead of design.

### 2.2.1 Creation of a new facility layout plan

In this section different methods found in literature used for layout planning are discussed. These processes can all be used to design a facility layout from the start and are called construction-algorithms. First, the process of designing a new facility is discussed, followed by a definition of block layout planning. There are many options and algorithms applicable to the facility layout planning problem; the following options are discussed: mathematical models, CORELAP, systematic layout planning, BLOCPAN, ALDEP, DISCON and SHAPE.

### *The process of designing a new facility layout*

Mateusz & Chien-Ho (2018) composed a framework for the design of a new facility layout based on an extensive literature review. The design process is divided into two phases; the construction phase and the diagnostic phase:

- Phase 1
  - Analysis of the parameters of the manufacturing process.
  - Selection of the optimization method.
  - Development of a facility layout project.
  - Preparation of the design of the manufacturing process in the digital model.
- Phase 2
  - Analysis of the digital model
  - Comparison of the available variants
  - Choosing the best solution
- Implementation of results

The proposed design framework involves the steps needed to construct a new facility layout. During the first phase, the process is analysed, an optimization method is defined, a layout is developed, and the design is prepared for evaluation. The selection of an optimization method is an important step in the design procedure, since it can greatly influence the results. A distinction in existing optimization methods can be made into strict and approximate methods. Exact methods are only applicable in the case of limited departments and location options (Santarek, 1987). Approximate methods offer a wider application and can be applied to larger problems. Exact algorithms are only feasible for small-scale problems, and cannot meet the requirements of practical construction (Lam, Ning, & Ng, 2007). Given the number of departments in the problem discussed in this report, the use of an approximate method is best fitting. Different modelling options are discussed in the following sections. When a optimization method is selected, a new layout can be developed. After developing a layout, the results are analysed and compared to other options. This comparison is then used to make a sound evaluation on the best option.

### *Mathematical models*

Mathematical models can be used to analyse all kinds of systems. Winston (2004) defines mathematical models as a mathematical representation of an actual situation that may be used to make better decisions or simply to understand the actual situation better. Mathematical models consist of an objective function, a set of decision variables and a set of constraints. The optimization model seeks to find values of the decision variables that optimize (maximize or minimize) an objective function among the set of all values for the decision variables that satisfy the given constraints (Winston, 2004). Methods like Linear programming (LP) models and mixed integer programming (MIP) models are examples of mathematical methods. MIP models are generally distance-based and work with the centroid of the departments. The centroids are shifted in such a way that all constraints are met and the objective is satisfied. For MIP models optimality cannot be guaranteed, since the optimal solution might require non-integer values. To solve a MIP a systematic is needed, a common approach is called Branch and Bound. A MIP model can be applied to the problem in this chapter, but given the fast amount of requirements on department positions to each other, the amount of options might be small.

### *CORELAP*

CORELAP stand for COmputerized RELationship LAYout Planning. CORELAP is one of the first construction algorithms to be computerized (Lee & Moore, 1967). The CORELAP algorithm calculation uses the proximity relationship expressed with Total Closeness Rating (TCR) as the basis for calculating the selection of department placement. The principle of the CORELAP Algorithm analysis is to determine the largest layout score, which shows that the relationship between departments is better (Tarigan, Cahyo, Tarigan, & Ginting, 2019). The TCR calculation is based on qualitative data from an Activity Relationship Chart, which is converted into quantitative data. The quantitative data is then

used to determine the first department to enter the layout. Subsequent departments are then added to the layout, one at a time, based on their level of interaction with departments already in the layout. Qualitative data is typically used only when it is too expensive or time-consuming to obtain numeric or quantitative data (Heragu, 2006). The advantage is that exact flow statistics are not needed to create a layout. The algorithm translates the importance of relationships between departments into a numerically evaluable model. This method reduces the need to gather data on the exact amount of movements on the terrain, which is hard given the dynamic situation at the terrain.

#### *Systematic Layout Planning (SLP)*

Systematic layout planning is an organized way to conduct layout planning (Muther & Hales, 2015). It consists of a framework of phases, a pattern of procedures and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout. The framework consists of the following phases: a pattern of procedures for step-by-step planning, and a set of conventions for identifying, visualizing and rating the various activities, relationships, and alternatives involved in any layout project. SLP lies at the base of many software packages that are developed to find good-quality layout options (Heragu, 2006). SLP is widely used and is a good candidate to apply for the construction of a layout for Van Gerrevink. This method yields good results and has a great framework that can be applied.

#### *BLOCPAN*

BLOCPAN stands for Block Layout Overview with Computer Planning. BLOCPAN is a departmental location system that includes random, construction, and improvement algorithms for developing layouts (Donaghey C. E., 1977). The layouts are graphically displayed and scored. The data required by this program includes the number of departments, their respective areas and a relationship chart (Ziai & Sule, 1988), it can make use of an activity relationship chart or a from-to-chart. BLOCPAN is a hybrid algorithm and can be used to create new layouts and adapt existing ones (Puspita, Igbal, & Pratami, 2016). When used as a tool for developing a new layout, BLOCPAN generates a random layout and uses an improvement algorithm similar to CRAFT (Section 2.2.2) (Donaghey & Pire, 1991).

#### *ALDEP*

Automated Layout design program (ALDEP) can be used to solve a block layout problem (Malmborg, 2013). ALDEP makes use of the following inputs: size of the facility, number of departments, size of the departments, proximity relationships and a sweep width. With these inputs ALDEP constructs a layout. The algorithm starts with a random department and places it in the upper left corner of the layout plan. The sweep width determines the initial department width, e.g. a sweep width of two and a department size of eight will result in a department of size 2x8. When the bottom of the first columns is reached, the algorithm continues at the bottom of the adjacent columns. This way of working results in a zig-zag pattern in the construction of departments. As a result from the random start, ALDEP can yield different results for the exact same problem. The next department is selected by finding the department that has the highest proximity rating with the last department. When there is a tie in proximity rating, the ties are broken at random. The scoring of the layout is done based on the proximity relationships. When two departments are adjacent in the layout, the weight corresponding to the rating between the two departments is added to the score. The process of forming and evaluating layouts is repeated several times and the best performing layout is chosen (Krishna, 2018).

#### *DISCON*

DISCON is an optimization algorithm that assumes all departments to be circular. The distance between departments is measured from centre to centre using the Euclidian distance. The algorithm starts by placing all departments in the centre point of the facility and then lets them “explode” outwards, this is the DISpersion phase. The purpose of this is to find a good initial solution. The second phase is the CONcentration phase. In this second phase the departments are concentrated as the constraints are tightened. The algorithm uses the area of departments and the cost of interactions between departments.

## SHAPE

SHAPE stands for Selection of materials handling equipment and area placement evaluation (Hassan, Hogg, & Smith, 1986). The objective of SHAPE is to develop a functional layout possessing minimal interdepartmental movement cost. SHAPE uses quantitative departmental relationships represented by a symmetric from-to chart. The first selected department is placed in the centre of the layout matrix, and the rest of the departments grow around it. The algorithm ranks all departments based on their relationship with the departments in the layout and uses this ranking to select a new department to enter the layout.

### 2.2.2 Redesign of existing layouts

In this section different methods used to improve layout planning found in literature are discussed. Improvement algorithms need an initial layout to adapt. These methods are best used for the construction of a layout based on the current situation. First, the process of reorganizing the facility layout is discussed. In the remainder of this section we discuss the following selection of improvement algorithms and heuristics: site layout planning, CRAFT, LayOpt and simulated annealing.

#### *The process of reorganizing the facility layout*

A study on available methods for workstation layout optimization by Mateusz & Chien-Ho (2018) provided a framework that can be followed during the adaptation process. The reorganization approach is longer than the approach for the design of a new facility layout. The reorganisation plan consists of four main stages: a construction phase, a diagnostic phase, an optimization phase and a control phase:

- Phase 1
  - Analysis of the parameters of the manufacturing process
  - Examining the settings of departments and relations between them
  - Development of a digital model of the analysed manufacturing process
- Phase 2
  - Analysis of the digital model
  - Identification of errors
- Phase 3
  - Selection of the optimization method
  - Development of an alternative layout of departments
  - Application of the optimisation result in the digital model
- Phase 4
  - Analysis of the digital model
  - Comparison of the available variants
  - Choosing the best solution
- Implementation of results

This framework is closely related to the one proposed in Section 2.1.1, the final phases are actual equal. The reorganisation of a layout means that existing relations must be taken into account and a model can be created and compared to the actual situation. After analysing the current processes, they can be modelled and errors in the model can be fixed. This base model can aid in the comparison of new options. A method to optimize the situation must be selected and alternatives must be developed. The newly developed layouts can be applied in the existing model and analysed. Form different comparisons the best layout can be selected.

#### *Site layout planning*

The task of finding an appropriate allocation for construction facilities is dubbed as site layout planning (Hammada, Akbarnezhada, & Reya, 2016). Hammada et al. (2016) compare three different models, namely the Forbidden region model, Open region model and Relaxed region model. For the Forbidden region model, a full representation of route mapping is provided where the forbidden region, modelled as the construction area building footprint, is taken into consideration, such that distance is measured based on corner mapping to prevent unreasonable travel paths on the construction site. This means

that the model tries to capture a realistic path planning approximation, where obstacles such as facilities are modelled and are taken into account as part of the constraints. The Open region model neglects the presence of a forbidden area and hence travel distance is assumed to be direct between facility centroids. For the Relaxed region model, a constraint generation algorithm is introduced where the design constraints of the Forbidden region model are first relaxed and then gradually added to the relaxed model. The objectives of site layout planning are the minimization of total flow cost, and the maximization of total closeness rating.

#### *CRAFT*

CRAFT stands for Computerized Relative Allocation of Facilities Technique and was introduced by Armour and Buffa (1963). The reasoning behind the CRAFT procedure is that, whereas it is infeasible to evaluate factorial  $N$  ( $N!$ )<sup>1</sup> different layouts, it is feasible to start with an initial layout and then evaluate all the different ways of exchanging two departments (Slack, Brandon-Jones, & Johnston, 2016). The CRAFT algorithm requires three inputs:

- A matrix of the flow between departments,
- A matrix of the cost associated with transportation between each of the departments,
- A spatial array showing an initial layout.

With these inputs, CRAFT determines:

- The location of the centroids of the departments
- The total transportation cost of the original layout
- The cost sequence of exchanging every possible pair of departments.

The exchange with the best improvement on transportation cost is then fixed. After the fixation of the new best found layout, the process of swapping is repeated until no further improvement is found (Krishna, 2018). CRAFT is found to be slightly superior performing compared to other algorithms (Drezner, 1980). The initial layout is of importance for the performance of this heuristic. Other starting positions might yield better available swaps.

#### *LayOPT*

LayOPT is an improvement algorithm for developing alternative and efficient block layouts from an initial block layout provided to the algorithm (Grajo, 1996). It is common that the initial layout is the existing or newly proposed layout. LayOPT is a steepest-descent, two-way exchange optimization routine. In each iteration, the algorithm exchanges the two departments that result in the biggest reduction of the objective function. The objective of LayOPT is to minimize the sum of parts flows times the appropriate costs and expected distances between all departments pairs.

#### *Simulated annealing*

Simulated annealing (Kirkpatrick, Gelatt, & Vecchi, 1983) is a method that can be applied to solve combinatorial problems like facility layout problems. It is used to find a global optimum in a large search space. The basic idea behind simulated annealing for this problem is to try different solutions and accept a worse solution with a certain probability, allowing the algorithm to escape local optima. The algorithm makes use of a cooling factor and an initial temperature. After a specified number of swaps or other changes, the temperature is lowered and the probability of accepting a worse solution is lowered. This continues until a maximum number of swaps, time limit or minimal temperature is reached. The exchange procedure is comparable to the procedure used in CRAFT (Chwif, Barretto, & Moscato, 1998).

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<sup>1</sup> For this we assume each department to have a size of 1, where  $N$  department are to be placed on  $N$  locations. The first department can be places on  $N$  locations, the second on  $N-1$ , the third on  $N-2$ , this sequence leads to a total of  $N!$  options to place all departments.

### 2.2.3 Conclusion

In this section we discussed multiple methods for the creation and adaptation of layout plans. We can use the knowledge combined in this section to define a suitable approach for the design of the new layout proposals in Chapter 4. It seems best to decide on the approach after completing the analysis of the current situation. The frameworks provide a guide in the process of designing a new layout plan, and the methods can be applied to create the plans.

## 2.3 Facility layout evaluation

Since it is not practical to evaluate different layout options in real-life, the use of modelling techniques to evaluate the layouts is needed. Given the size and complexity of the components in the layout, we cannot simply move them each week to find the best option. With the use of models, different layouts can be evaluated without incurring the cost and downtime of a real-life adaptation. Before looking into the different methods used for facility evaluation, research is conducted to gain knowledge on different available modelling techniques. From these modelling options, a choice can be made for the best suitable method. Some background information on mathematical modelling and definitions can be found in Appendix A. This section is used to elaborate on methods used in literature to evaluate facility layouts. To get an idea about what is important when designing facility layouts, we first discuss common objectives and criteria for evaluation. Next, the objectives for optimization are discussed, followed by a section on layout performance assessment. This section is ended by an overview of methods used to gain information on facility utilization and a conclusion.

### 2.3.1 Modelling techniques

In this section a description of modelling techniques commonly used in operations research is given. Much research is done in the field of production facility performance evaluation, and different methods are evaluated. Although the company might not look like a production facility at first sight, there are lots of activities on the terrain to process incoming materials. Suri et al. (1993) place the main approaches to production network performance evaluation in three main categories: static (allocation) models, aggregate dynamic models (ADMs) and detailed dynamic models:

1. *Static (allocation) models*. These models add up the total amount of work allocated to each resource, and estimate performance from these totals. With these models, most of the dynamics, interactions and uncertainties typically seen in manufacturing systems are mostly ignored. It can however be useful as a rough initial estimator of system size and performance.
2. *Aggregate dynamic models (ADMs)*. These models account for some of the dynamics, interactions and uncertainties in the system, but in an aggregated way. Typically, analytical techniques from stochastic processes, queueing theory, queueing networks and reliability theory are used. performance is often documented based on steady state averages. Still, these models tend to give reasonable estimates of performance and are relatively popular.
3. *Detailed dynamic models*. These approaches model the manufacturing system to the level of detail desired by the analyst. Detailed dynamic models can be further divided into two categories: deterministic and stochastic. A deterministic model is one in which the values for the dependent variables of the system are completely determined by the parameters of the model. Stochastic models introduce randomness in such a way that the outcome of the model can be viewed as probability distributions rather than unique values (Rey, 2015).

From this overview of modelling techniques, we can see that there is a range of options available to evaluate the performance of a system ranging from very simple ones to profound models. The use of static models can aid in the basic understanding of the system. With the data from the weighbridge and the statistical records, a construction of the current situation can be made. This information can be used to gain insight in the current processes and workloads. There are no dynamic parts in these models and thus it would not be suitable to use these kind of models to evaluate all characteristics. With the results from the static models it would be possible to find bottlenecks on the terrain without going to much in detail. At the yard of Van Gerrevink each day is different, and the found layout must

yield a solution that is capable of delivering an improvement in this dynamic situation as opposed to for one situation only. Given that the processing times at the locations are simply not deterministic, the use of static models for the evaluation of the layouts will not be sufficient. For the further evaluation the need for more sophisticated models arises. Most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical model that will be evaluated analytically (Law, 2015). Simulation tools offer great versatility in levels of detail and the recording and evaluation of KPIs.

For the evaluation of the newly developed layouts and the current layout, the use of stochastic simulation is a good choice. It offers great adaptability and each of the processes on the yard can be modelled to the desired level of detail. Simulation is an important technique used by analysts to validate or verify suggested improvements for manufacturing processes and to verify that suggested conditions or configurations satisfy design specifications (Curry & Feldman, 2011). Because of the great versatility, flexibility, and power, simulation is one of the most widely used operations research techniques (Ryan & Heavey, 2006). By evaluating the layouts under different situations, the characteristics like average and peak performance can be estimated. A discrete event simulation (DES) works with a discrete sequence of events in time. The state of the system only changes upon one of these events. When the event has happened, the time until the next event is skipped and that event will happen. The benefit of this is that the state of the system only has to be determined at an event and not during the time between events, this is beneficial for running time of the simulation. Discrete event simulation uses a clock and an event list to progress in time, the clock forwards the time to the point of the next event on the event list.

### 2.3.2 Layout objectives and criteria for evaluation

First, we need to define what identifies a good layout and how this can be evaluated. The layout of a facility can determine the performance of the facility to great lengths. A bad layout can result in inefficiency thus increasing costs. From literature, many criteria for layouts can be found. The evaluation of a layout should examine the main characteristics before the operation starts to avoid high costs and loss of time caused by the re-layout process (Sagnak, Ada, & Kazancoglu, 2018). A good layout enables a good and natural flow of materials. Many objectives can be defined when designing a layout, a selection is given (Slack, Brandon-Jones, & Johnston, 2016), (INC, 2020), (Okpala & Chukwumuanya, 2016), (Muther & Hales, 2015):

- Inherent safety
- Security
- Length and clarity of flow
- Minimize delays
- Reduce work-in-progress
- Accessibility
- Space utilization
- Use of capital
- Image
- Ease of future expanding
- Ease of communication and support

The identified objectives must be kept in mind when designing a new facility for Van Gerrevink. We identify the most important criteria to be the minimization of delays for internal logistics and clients, inherent safety and space utilization. These criteria combine well with others like improving length and clarity of flow. To be able to evaluate the different layouts and compare them to one another, a set of evaluation criteria is needed. The listed criteria can be used to score the layouts and determine which would be the best fitting. Scoring can be done using for instance the analytic hierarchy process (AHP), which is a powerful but simple method to make ranking decisions. In this method, criteria are assigned a weight and for each layout a score is assigned, the layout with the best total score is selected.

### 2.3.3 Optimization objectives

There are many objectives that can be optimized, this leads to many different options in layout design. Mostly one objective is chosen to optimize, since another objective would likely result in another layout. A combination of objectives is also possible, for instance to reduce the number of movements between two departments, but with minimal relocating costs. The combination of multiple objectives will lead to a trade-off between choices. The optimization problem is usually solved with one criterium an occasionally with a combination of criteria (Mateusz & Chien-Ho, 2018) (Lis, 1980) (Dira, Pierreval, & Hajri-Gabouj, 2007):

- Minimization of transport or mass of transported details,
- Minimization of transport routes
- Minimization of the number of transport operations
- Minimizing transport costs
- Minimizing the costs of locating departments
- Minimizing traffic congestion
- Minimizing shape irregularities

These objectives can all be used to steer on the best solution for the company. Many of the algorithms found in literature are designed to optimize one of these objectives. Most of the algorithms focus on a reduction of transportation. In the situation of Van Gerrevink the focus lies on minimization of traffic congestion and the minimization of total driving distance.

### 2.3.4 Layout performance assessment

The goal of individual departments is not to strive for efficiency and cut costs alone, in that case it would be best to do nothing. There is also a responsibility towards the customers and other departments, and this calls for the need to quantify the department's effectiveness (Andersson, Aronsson, & Storhagen, 1989). Where the creation and adaptation of layouts is widely discussed in literature, the evaluation of these layouts is less commonly discussed. Caplice & Sheffi (1995) provide a review on and evaluation of logistic performance measurement systems, although this is an old article, the basics are still relevant. They selected six criteria as being the most relevant when evaluating a logistics performance system. A "good" system should be comprehensive, causally oriented, vertically integrated, horizontally integrated, internally comparable, and useful.

Sagnak et al. (2018) provide a conceptual framework for the assessment of layout performance. The proposed framework incorporates and integrates tangible and intangible criteria related with cost, flow, flexibility, surrounding environment, environment quality, time and characteristics. All of the criteria mentioned before can be further specified into sub-criteria. These criteria and proposed sub-criteria can be used for the formulation of KPIs.

### 2.3.5 Methods known to gain information on facility utilization

In this section some methods to gain information on facility utilization are discussed. Many tools originate from the lean methodology, which focusses on always improving and thus finding flaws in the system. We discuss the use of a spaghetti diagram, centre of gravity analysis, lean methods, the activity relationship chart and the space relationship chart.

#### *Spaghetti diagram*

A lean methodology to track routings on the yard is the spaghetti diagram. This diagram consists of a graphic reproduction of the architectural floor plan of a structure, where lines are drawn from one space to another, representing the path taken by employees, customers, and objects along a particular process. It allows documenting and visualizing the physical flow in order to identify wasteful motion or transportation, architectural barriers, and improvement opportunities to expedite process flow. The drawbacks of spaghetti diagrams are that information about the movements can be hard to obtain and it is time consuming to make the diagrams.

### *Centre of gravity analysis*

A centre of gravity analysis can be used to determine which departments are most important. Large departments will attract more movement and thus increase logistics. The larger the department in terms of throughput, the larger the amount of movements will be. By analysing the throughput of the departments, high throughput departments will be the core of the company and deserve more attention than a small department that has a limited number movements. Centre of gravity analysis is more commonly used to find the optimal location of for instance a warehouse in a new region to supply customers at minimal overall cost.

### *Identifying waste using lean*

In the lean principles it is common to seek for improvement by reduction of waste, also referred to as Muda (Theisens, 2018). Lean identifies the following eight forms of waste:

- Over-production, producing more than asked by the market
- Waiting, idling or defect equipment
- Transport, transporting materials or products
- Over-Processing, taking unneeded steps to process parts
- Inventory, unnecessary supplies or stock
- Movement, searching, unnecessary movements
- Defects, faults, scrap or bad quality
- Unused expertise, not using existing expertise or knowledge

Some forms of waste can be identified at the yard of Van Gerrevink, waiting and transportation are main issues. By looking through the processes there might be more forms of waste that can be discovered.

### *Activity relationship chart*

The relationship chart provides an overview of the interactions between all departments. The importance rating of the interaction between two departments is denoted by a vowel rating, this rating goes from A-“absolutely necessary” to U-“unimportant”. An “X” indicates that the interaction between two departments is prohibited or undesirable. Numbers are used to indicate the reason of the rating. The activity relationship chart is used as a base for many of the algorithms in order to score layout performance in the absence of quantitative data. This method is applied in Section 3.2.8.

### *Space relationship diagram*

The space relationship diagram is an important step for many algorithms and heuristics. The space relationship diagram might be the single most effective aid to layout planning (Muther & Hales, 2015). The departments are drawn to scale and the intensity of flow between them is indicated. These diagrams are best used when material movement dominates the project.

## 2.3.6 Conclusion

In this section, methods, objectives and criteria for optimization are discussed. Different approaches are discussed, and discrete event simulation provides the best tools to analyse the options. In the second part, the minimization of delays for internal logistics and clients, safety, and improved space utilization are identified. As optimization objective, the minimization of transport routes and total driven distance is identified. The performance of the facility can be measured by KPIs, which have to be specified for this project. A spaghetti diagram can be used to gain insight on the movement of staff and vehicles on the terrain and is a good first step into analysing the current situation. The centre of gravity analysis can be used to find out where on the terrain movements concentrate. Lean principles can be applied to identify waste and reduce or even remove this. The activity relationship chart and space relationship diagram are used in many of the heuristics that improve facility layouts. These methods provide a way to quantify the relations between departments, they also help in the understanding of interdepartmental relationships.

## 2.4 Conclusions

With the knowledge collected in this chapter, we can answer the sub-question: “What does literature say about facility layout design, optimization and evaluation of performance?” At Van Gerrevink multiple types of layout problems can be determined, from the complete compound down to individual departments. Most important are the manufacturing and warehousing characteristics. The location can be seen as a job-shop with batch-processing. We also concluded that most of the processes at Van Gerrevink can be seen as a push system where the incoming vehicles push materials into processing system. This method of working is inherent to the type of business. The processing of waste is a service that is done based on customer demand.

To evaluate the final layout proposals, we can make use of static models, aggregate dynamic models, and detailed dynamic models. From these options the use of a detailed dynamic model in the form of a discrete event simulation seems best fitting.

In literature we found many different heuristics and algorithms to create and adapt layout plans. A distinction can be made between construction and improvement algorithms. For the greenfield solution, we first apply a construction heuristic, followed by an improvement heuristic. The construction heuristic is used to create an initial layout, which the improvement algorithm tries to improve. For the adaptation of the current layout we apply improvement heuristics, since the initial layout is given.

We aim to reduce the total number of movements needed on the terrain to fulfil all needs. By reducing the needed amount of transports there is less traffic, which results in less waiting. By reducing the amount of movements it is also important to keep an eye on the total distance driven each day, by reducing this there are less kilometres driven resulting in less pressure on staff, less wear on machinery and a reduction in fuel consumption. Reducing the time needed by an operator to finish its movements also frees time that can be spent in keeping the terrain clear improving the environment and creating a safer working environment.

### 3. Current situation

In this chapter, the current situation of Van Gerrevink is discussed. A general overview of the location and layout are presented in Section 3.1, including a discussion on existing plans for a remodel of the current layout and descriptions of all departments. Following the section on facility layout, we discuss data collection and analysis in Section 3.2. In Section 3.3 the key performance indicators are determined. The conclusions are given in Section 3.4.

#### 3.1 Facility layout

Figure 3-1 shows the current location of Van Gerrevink, where part of the processes are located indoor and the rest of the activities are carried out outdoor. From Figure 3-1 it becomes clear that many different operations are carried out at different locations. The amount of work and movement of machinery and materials makes that it can be very busy on the location and vehicles have to wait on each other. All data is based on the situation depicted in Figure 3-1 and Figure 3-2.



*Figure 3-1 Current situation at Van Gerrevink*

##### 3.1.1 Results from previous work

In an earlier research done by the company, all employees were asked to draw their vision of the perfect layout on an empty shell of the company layout. From these results it became clear that the weighbridge at the middle of the terrain caused congestion and delays. Since all vehicles have to pass the weighbridge when entering and leaving the terrain, it is a busy place. The current location makes it that vehicles waiting to enter the weighbridge block routes of internal transportation and hinder other vehicles. In the current situation as depicted in Figure 3-2, the weighbridge and weighing office can be found in the middle at number 3. Previous to the start of this project, a decision was made to remodel the layout as is displayed in Figure 3-3, where the weighbridge and weighing office are located at the entrance opposite to the main office. Clearing the centre part of the terrain will increase manoeuvring space and reduce queueing at the central part of the terrain. Having the weighbridge at the entrance allows access control to limit the amount of vehicles on the terrain and drivers can be provided with routing information before entering the terrain.

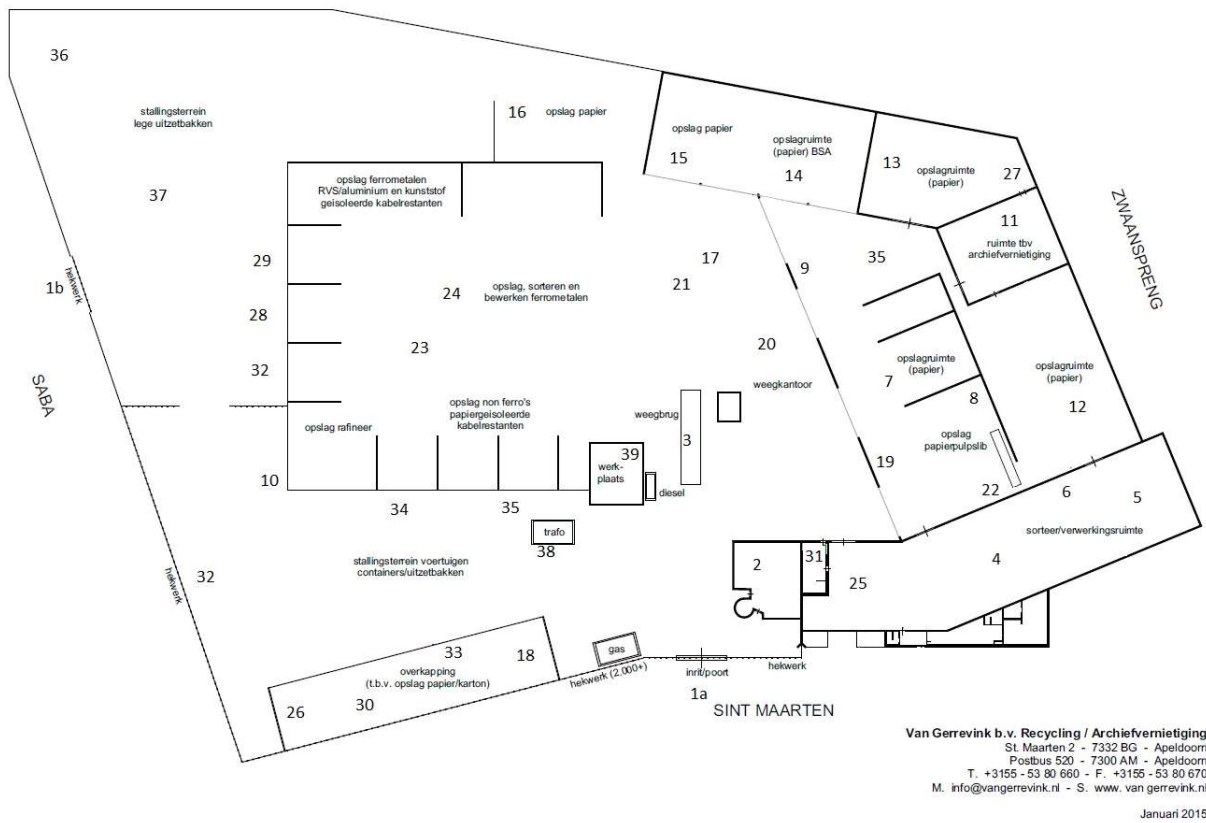


Figure 3-2 Starting situation, with numbering

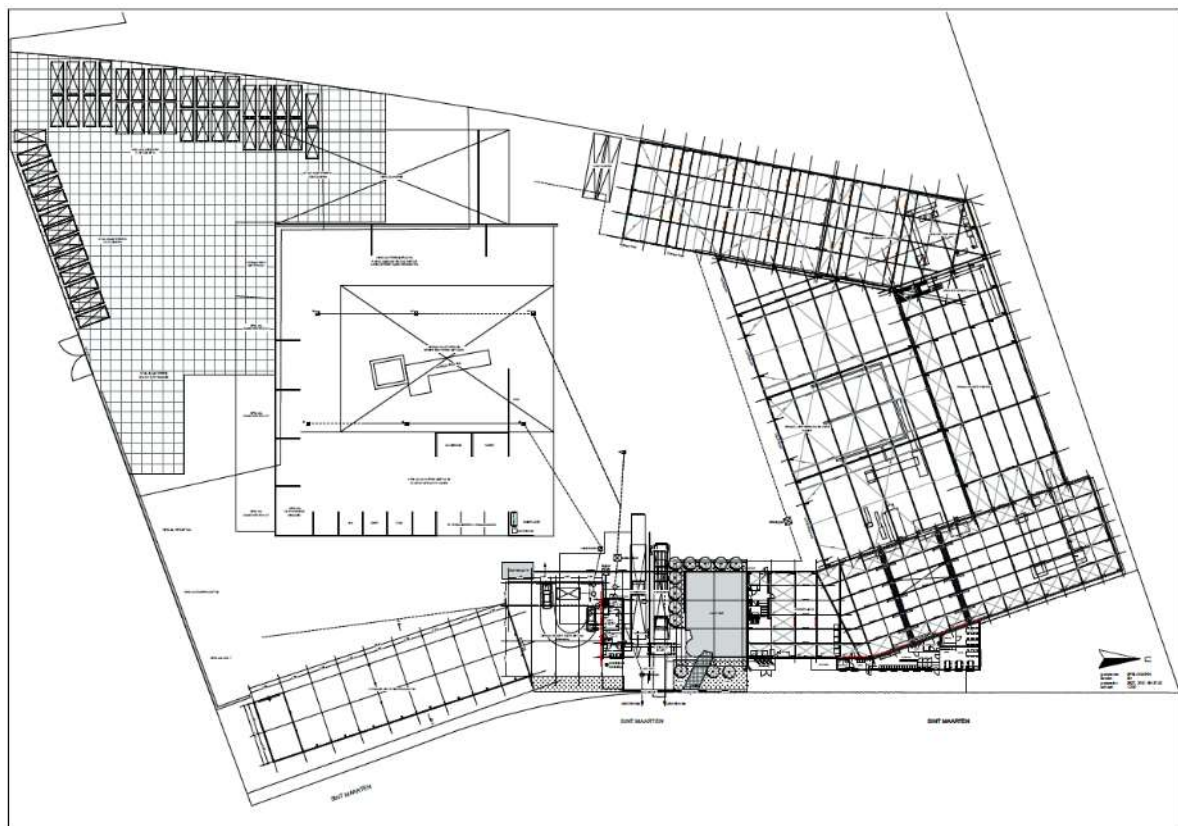


Figure 3-3 Existing remodel plan

### 3.1.2 Departments

In this sub-section the different departments and important locations at the yard of Van Gerrevink are discussed. In Table 3-1, an overview of all departments is provided. The numbers correspond to the numbers in Figure 3-2. The table also provides the main material that is processed at the location, the assigned category and the required amount of space per department. The assigned category is used in the redesign of the layout to determine if a location can be moved. Figure 3-3 provides a short description of the used categories. The space requirement is determined based on existing layout documentation, areas are approximations and do not explicitly include driving paths. The total area reserved for the departments is 11,000, which is 55% of the approximate 20,000m<sup>2</sup> available. A total of 39 departments is considered, which leads to a total of 39! (2.04\*10<sup>46</sup>) layout options.

Table 3-1 Department overview

Department	Number	Main material	Cat.	Space required [m <sup>2</sup> ]	Special requirement
Entrance	1	All	D	15	At the edge of the terrain
Office	2	-	D	150	
Weighbridge	3	All	B	100	Accessible for all vehicles
Paper unloading HBC125	4	Paper	C	665	Must be located next to HBC125 press
Paper press HBC125	5	Paper	B	315	Indoor
HBC125 shredder	6	Paper	B		Close to HBC125 press, indoor
Paper unloading HBC80	7	Paper	C	120	Must be located next to HBC80 press
Paper press HBC80	8	Paper	B	115	Indoor
High quality paper Bunker	9	Paper	A	50	indoor
Loose paper storage	10	Paper	A	60	
Secure data Destruction	11	Paper/ all	B	260	Indoor, closed department
Bale storage 1	12	Paper	A	360	
Bale storage 2	13	Paper	A	220	
Bale storage 3	14	Paper	A	355	
Bale storage 4	15	Paper	A	355	
Bale storage 5	16	Paper	A	870	
Bale storage 6	17	Paper	A	150	
Bale storage 7	18	Paper	A	180	
Reel splitter paper	19	Paper	A	50	Indoor
Loading bridge	20	Paper	A	60	Space for truck
Loading area paper bales	21	Paper	A	110	
Dust extractor	22	Paper	B	70	Indoor, close to balers and shredders
Scrap yard	23	Metal	B	3,170	Liquid proof floor
Scrap shear	24	Metal	B	80	Within scrap department
Metal purchasing	25	Metal	A	195	Indoor , closed department
Small metal storage	26	Metal	A	70	Indoor, closed department
WEEE- processing	27	WEEE	A	200	Indoor, closed department
Wood A-Class	28	Wood	A	90	Not close to buildings
Wood B-class	29	Wood	A	90	Not close to buildings
Waste sorting	30	Residual waste	A	135	Indoor, space for containers
Archive individuals	31	Data	A	8	
Plastics	32	Plastic	A	400	
Reel splitter glass fleece	33	Glass fleece	A	50	Indoor
Pallet storage	34	Pallets	A	100	Not close to buildings
Packaging storage	35	Packaging	A	250	
Container yard	36	Containers	A	1,650	
Truck and trailer parking	37	-	A	-	Currently no fixed location
Transformer house	38	-	B	20	
Workshop	39	-	B	112	Indoor

Table 3-2 Department categories

Category	Description
A	Free to move
B	Hard to move
C	Connected to other department
D	Fixed location

### 1. Entrance

The company terrain has one main entrance [1a] and a smaller gate for own vehicles [1b]. All vehicles not belonging to Van Gerrevink enter and leave the terrain using the main entrance. The smaller gate is normally closed and is occasionally used by the drivers of the container trucks when they don't have to weigh and want to enter or leave the terrain. At the main entrance a radiation detector is installed to monitor incoming materials on radioactivity, this check is especially important for incoming metals.

### 2. Office

The office building is housing all supporting services like planning, financials and management. Facilities like the canteen and restrooms are connected to the office building.

### 3. Weighbridge

The weighbridge is one of the core locations at the yard of Van Gerrevink, literally and figuratively. All incoming and outgoing vehicles pass the weighbridge to register the weight in the vehicle. This registration is used to keep track of the materials processed by Van Gerrevink. All vehicles are weighed at the weighbridge when they enter the terrain and again when they leave. This weighing is important for the company since they must account for outgoing materials and prices are determined based on the weight of the materials. The weighmaster registers data about each transport, like which company and truck performed the transport, the main waste flow category, material group and the material itself. During the second weigh, the system registers the new weight and time of departure.

### 4. Paper unloading HBC125 / sorting

The unloading area at the HBC125 is an important location. This is the main unloading area for all incoming trucks with paper. At this location a crane is used to move the unloaded paper into the conveyer leading to the press. It is important that this location is accessible to trucks so materials can be unloaded as close to the conveyer as possible to minimize the workload of the crane. The current location of the conveyer might not be ideal, since trucks have to backup into the warehouse through two doors. The current location can be accessed by a maximum of two trucks when there is room in the warehouse and the drivers wait for each other. For the walking floor trailers, the location is poorly accessible and the location is blocked for other trucks over a longer period of time.

### 5. Paper press HBC125

The HBC125 is the biggest bale press at Van Gerrevink, the paper types with the biggest flows are processed by this press. The bales produced by this press are stored at multiple locations on the terrain. All paper and cardboard collected from households and companies is processed by this press. Van Gerrevink also provides a bale making service, in this construction the company does not buy the paper, but only processes the paper to bales on request of a client.

### 6. HBC125 shredder

The HBC125 shredder is located next to the HBC125 paper press and can be used to shred paper to a smaller format. The shredder must be connected to the intake of the press.

### 7. Paper unloading HBC80

The paper unloading bunker is situated next to the small bale press and is used for special types of paper that are processed at the HBC80 press.

#### *8. Paper press HBC80*

The HBC80 is the smaller bale press of Van Gerrevink. This press is mostly used for the more special types of paper and higher qualities which are delivered in smaller quantities. Archive papers and other papers that must be destroyed are fed to this press after destruction. The shredded paper is mixed and baled.

#### *9. High quality paper bunker*

The high quality paper bunker is used to temporarily store and sort paper of high quality. This material is used to upgrade the quality of bales from the HBC80 when the quality of materials processed by the shredder is too low. Paper in this bunker is fed to the HBC80 shredder.

#### *10. Loose paper storage*

The paper bunker for individuals is located at the opposite site of the terrain opposed to the balers. Individuals and businesses coming with small amounts of paper and/or cardboard are sent to this location. By having this additional unloading locations the main place at the balers can be kept free for trucks and larger loads. The use of this location has the drawback that the materials have to be moved to the balers. This is done by loading the paper into a container using a crane and using a truck to move and unload the container. Working in this way creates additional work for a crane and a truck, both of these vehicles have to move across the terrain multiple times to process the unloaded materials.

#### *11. Secure data destruction*

This is a closed location which houses the shredder connected to the HBC80 bale press for paper and a dispenser to fill big bags or crates. This department processes all confidential materials. Material destruction and department standards are according CA<sup>+</sup> regulations. This department houses the shredder belonging to the HBC80 baler.

#### *12. Bale storage 1*

The storage of paper bales is divided into seven different locations. There is a difference in storage requirements between types of paper bales. Good quality bales are stores indoor, while bales of lesser quality can be stored outside. Bale storage one is the closest to the exit of the balers and is used to store good quality bales. The height of the current location is a limiting factor.

#### *13. Bale storage 2*

Bale storage 2 is currently located in a closed off section together with WEEE processing. This is an excellent location for high quality bales, there is enough height and the department is closed.

#### *14. Bale storage 3*

Bale storage 3 is a semi-closed location. It is used for better quality bales.

#### *15. Bale storage 4*

Bale storage 4 is a semi-closed location with one open side. Bales are stored under a roof, but can be affected by weather in severe conditions.

#### *16. Bale storage 5*

Bale storage 5 is located next to the scrap yard. There is a large amount of space available for the storage of bales. Bales at this location are stored in the open air and are of common quality.

#### *17. Bale storage 6*

Bale storage 6 is comparable to storage location 5, but located closer to the loading bridge and warehouses.

#### *18. Bale storage 7*

Bale storage 7 is located in the small warehouse at the south side of the terrain. It is used for small amounts of special products.

#### *19. Reel splitter paper*

Rejected rolls of paper from factories are collected and processed at the reel splitter. The large sheets of paper need to be cut so the material can be processed at the balers. The reel splitter is operated by an operator and must be located indoor.

#### *20. Loading bridge*

The loading bridge is used by forklifts to access containers and trailers for unloading and loading of paper bales for transport. A loading bridge is a simple piece of equipment which can be moved relatively easy. Currently the loading bridge is located between the warehouse and some other storage, so it is relatively close to the storage locations.

#### *21. Loading area paper bales*

The loading area for paper bales is located close to the weighbridge. Tautliners are loaded by a forklift at this area. There is no fixed location, but the trailers are usually positioned at the same location. The trailer is opened from the side, and the forklift is used to place the bales in the trailer.

#### *22. Dust extractor*

The dust extractor is an important piece of equipment to control emissions and keep the air clean. Next to emissions control, the dust extractor is also used as way of transporting shredded paper from the secure data destruction department to the HBC80 press.

#### *23. Scrap department*

At the centre of the terrain lies the scrap department. The scrap department is where all ferro-metals are processed and stored. The floor must be water tight because the metals can contain oil residues which must be contained and may not flow into the ground.

#### *24. Scrap shear*

The scrap shear is used to cut large pieces of metal into smaller pieces. This piece of equipment is located at the centre of the metal yard and can be seen as part of the metal yard department. It is convenient to have this machine close to the storage of small metal parts to minimize handling.

#### *25. Metal purchasing and sorting*

Metal purchasing is where individuals can bring their metals to be sorted and weighed. This department is located between the office and the paper unloading area. A forklift is used to move small containers with metals from this location to the storage and the metal yard. Individuals park their cars, often with a small trailer, at this location, which can block access to the paper unloading area for small amounts of time.

#### *26. Small metal storage*

The small metal storage is a closed warehouse located in the newest shelter. This storage is used to securely store bins with valuable metals. The metals originate from the metal purchasing and are moved with a forklift.

#### *27. WEEE-processing*

At the WEEE processing location all kinds of electronic devices are disassembled and sorted. This is an important step in the recycling process of electronics. This department is currently located in the old warehouse adjacent to the shredding department. This department does not need large specialised equipment and can be easily moved. Given that most of the work in this department is manual labour, it is desirable to create a comfortable working environment.

#### *28. Wood A-class*

A-class wood is non-impregnated, unpainted and untreated wood. This is the best class of recyclable wood. This type of material is only temporarily stored at the yard until there is enough to fill two containers and the material can be sent away. This material can be brought in by individuals and companies and a small part is retrieved from the sorting of incoming waste flows.

### *29. Wood B-class*

B-Class wood is wood of lesser quality, which can serve as a good raw material for the production of for example pallet, blocks and chipboard. When the pieces are of lesser quality the materials can be used as biofuel to generate durable energy at bio-energy stations. This type of wood is also brought in by individuals and companies and some originates from sorting processes on the yard. B-class wood is stored next to the A-class and is accumulated until there is enough to fill a full truck to take it away.

### *30. Waste sorting*

Residual waste is brought in by the waste collection companies and by container trucks. This material is sorted and transferred into larger containers using a crane. Materials are only stored temporarily and sent away when a full truckload is available. Materials are stored inside to reduce materials being blown away in the wind and decrease the unpleasant view for surrounding companies.

### *31. Archive individuals*

The archive material intake is located between the offices and the metal purchase department. People often park as close to the entrance as possible, and given the small area where all departments come together. This creates situations where trucks and internal transport have to move around parked cars which leads to delays and safety issues.

### *32. Plastics*

Plastics are stored in bunkers at the south side of the terrain, close to the open warehouse. These material are stored until there is enough to fill a truckload.

### *33. Reel splitter glass fleece*

The reel splitter at Van Gerrevink is used to cut large items in smaller pieces for further processing. Common items are roles of paper and glass fleece, which are cut to small sheets and stored in a container until there is enough and the material can be taken away.

### *34. Pallet storage*

The pallet storage is located at the side of the scrap yard and used to store pallets. Pallets are found during the sorting processes, are brought in and are used to hold materials supplied at Van Gerrevink. When there is enough stock of pallets they are sold.

### *35. Packing storage*

Packaging is used by Van Gerrevink to transport and collect materials. Containers are rented to customers and exchanged for an empty one when full. In order to service customers a supply of different packaging containers must be kept on stock. Currently bins mainly stored next to the scrap yard and in the large warehouse.

### *36. Container yard*

The container yard is used to store empty containers that fit on the trucks owned by the company as well as the trailers that go behind the trucks. Empty containers must be kept in stock so clients can quickly be serviced when a request is made. Full containers at the client can be exchanged with an empty one taken from the yard, this reduces the need for an empty trip and the client always has a container at his disposal. The container yard uses a considerable amount of space since each container has a footprint of about 16 m<sup>2</sup> and space is needed to load the container on the truck. When there are around 50 containers on the yard this covers 5% of the terrain excluding space to manoeuvre and space between containers for access.

### *37. Truck and trailer parking*

Trucks and trailers are parked on multiple locations on the terrain, there is no fixed location. The trailers are usually parked at the container yard, where they sometimes block access to containers. Trucks are in use during the day and at the end of the day they are mostly parked around the weighbridge. It might be beneficial to assign parking places to the trailers to prevent blockage.

### 38. Transformer house

Electricity to the yard goes through this transformer. Power from the net is transformed and divided to the locations on the terrain. The transformer house has a fixed location and can be moved only at high cost. Relocating and renewing the transformer house will have an estimated cost in excess of €120,000 excluding VAT.

### 39. Workshop

The workshop is used for maintenance and service requiring all kinds of tools. The building is not used to process materials and is a supporting department necessary to operate and maintain machinery.

#### 3.1.3 Department clustering

In this section we discuss the departments that can be clustered during the creation of the alternative layouts. This is done by combining machinery, equipment and departments with comparable materials. By combining these locations, the workload of layout creation and evaluation is reduced and constraints are always met.

Entrance, office and archive intake for individuals can be clustered. The entrance and office are great to be taken together, both should be located at the entrance of the terrain to allow easy access. By locating the office next to the entrance, it allows visitors to report their arrival. It also means office staff does not have to cross the yard to reach the office. The archive intake is staffed by office staff, thus should be close to the office. Having the archive intake close to the entrance reduces presence of cars on the remainder of the yard.

Incoming paper that is processed at the HBC125 is sorted and then pressed. Therefore the unloading of the trucks and the sorting area are seen as one location. After sorting, the materials are fed into the baler using a crane. To minimize handling, trucks unload as close as possible to the baler. The HBC125 shredder is mounted on the baler and can thus also be seen as one machine.

The paper unloading bunker for the HBC80 and HBC80 baler are put together to minimize handling of material. A crane is used to feed the baler and this machine has a limited range at which it can work efficiently.

The scrap shear and scrapyard are clustered since they process the same materials. To minimize handling it makes sense to place the shear as close as possible to the material it has to process. Furthermore, both departments must comply with the same environmental regulations.

Both wood classes are clustered, since these are processed in a similar way and this makes it easier to sort materials that arrive to the yard.

Pallets and packaging are seen as one. In practice these materials are stored all around the terrain to reduce driving with the forklifts. There is however a main storage that is used when the smaller stacks reach a certain level.

## 3.2 Data collection and analysis

This section describes the processes of data collection and the initial results. We make use of existing data taken from the company database, this includes company statistics and data from the weighbridge. Additional data is acquired by measuring and tracking. The main activities of the company are the collection and processing of waste flows. To facilitate the processing of all these materials, lots of vehicle movements are needed. Over the period between 02-01-2017 and 17-02-2020, the location of Van Gerrevink processed about 100 vehicles on average each working day. First, we discuss the main material groups used in this report. Next, movements and time spent on the terrain per vehicle class are discussed. For the analysis we make use of the data from the year 2019, this makes the data easier to interpret and compare the results with the company registrations, since the company keeps records on a year-to-year base.

### 3.2.1 Materials

Van Gerrevink processes a wide variety of materials and has many different storage and processing departments. Some materials are processed and received at multiple locations at the yard, Table 3-3 provides the most used location where the material is processed, the numbers refer to the locations shown in Figure 3-2.

Figure 3-4 shows the distribution of the number of movements of different materials over the weighbridge. From the diagram it becomes clear that about 50% of movements originates from paper, the core business. Metals are a strong second with over 30% of total movements. The data about weighbridge movements can be divided in incoming and outgoing movements. Materials entering the terrain are registered as incoming, materials that are sold are registered as outgoing. Figure 3-5 shows the difference between incoming and outgoing movements in percentages.

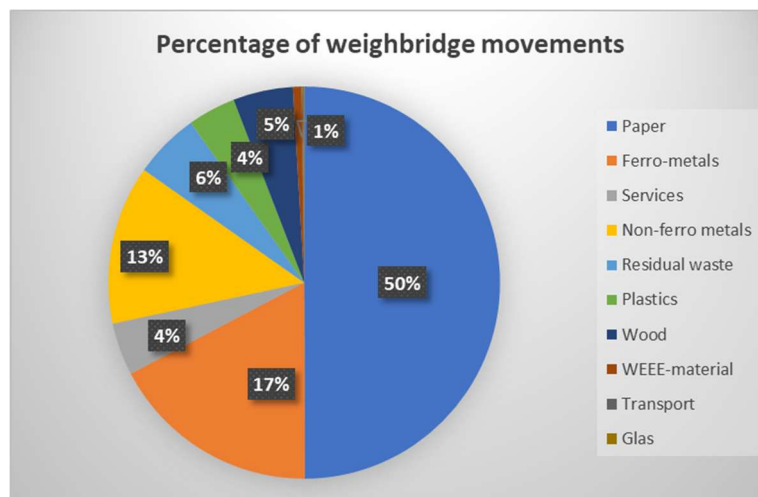


Figure 3-4 Material movements on the weighbridge

Table 3-3 Common routing of incoming materials

Material	Common location
Loose paper	Paper hall [4]
Ferrous and non-ferrous metals	Scrap department or metal purchasing [23/25]
Wood	Wood storage [28/29]
Residual waste	Waste container [30]
Paper to be processed (roles and bales)	Paper storage [10/19]
Archive and confidential material	Secure data destruction [11/31]
WEEE	Metal purchasing / WEEE-processing [25/27]

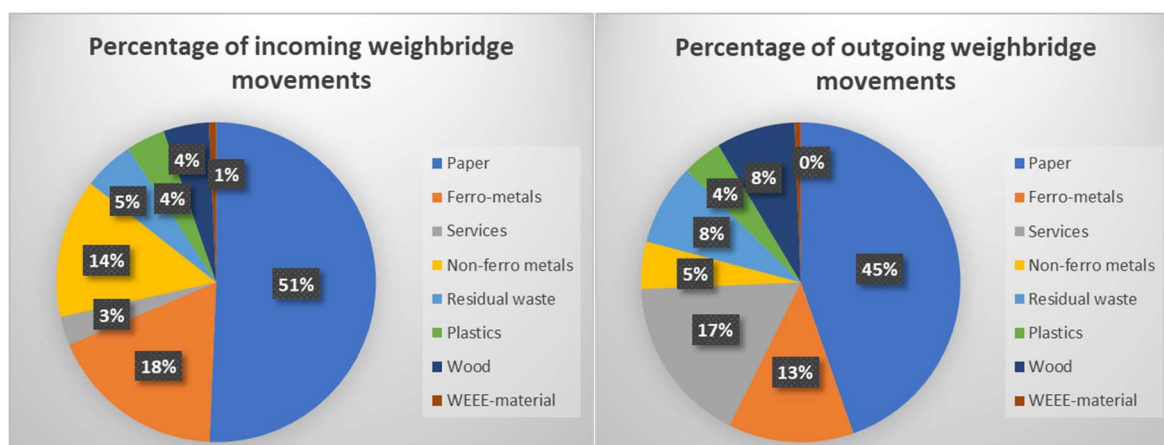


Figure 3-5 Comparison of incoming and outgoing vehicle movements

### 3.2.2 Movements based on vehicle class

Using the data from the weighbridge and the regulations of vehicle weight as provided by the Netherlands Vehicle Authority (RDW), an estimation of the type of vehicle entering the terrain can be made. Three classes are distinguished and listed in Table 3-4: B, C1, and C. These classifications are used to distinguish between vehicle classes. We assume that the class C1 and class C vehicles belong to companies. For the class B vehicles this distinction is less clear, most individuals will drive in a class B vehicle, but there are also a lot of class B company vehicles. It is more important to be able to classify vehicles as truck or car given that the vehicle class has most influence on the movements and processing times.

Table 3-4 Vehicle classifications (RDW, 2020)

Class	Name	Min weight [kg]	Max weight [kg]
B	Car	0	3,500
C1	Light truck	3,500	7,500
C	Truck	7,500	50,000

Table 3-5 shows the number of registered vehicles in the years 2017, 2018, 2019 and an expectation for 2020. In the first years, a steady increase in volume can be seen, the expectation for 2020 is lower. The expectation is based on the first 83 days of 2020 and this trend is continued to the rest of the year. This method disregards seasonality and the effects of the corona pandemic are not clear resulting in a rough estimate.

Table 3-5 Movements based on vehicle class and all data registrations \*indexed

Class	Total movements 2017	Total movements 2018	Total movements 2019	Expectation for 2020
B	18,872	20,073	19,569	19,757
C1	5,365	3,704	3,806	2,860
C	48,474	50,724	53,631	51,952
Total	72,711	74,501	77,006	74,566

For each vehicle type and material, the total arrivals over 2019 are used to determine the average per day. To model the arrival process, we make use of the negative exponential distribution. This distribution represents the time between events in a Poisson process. The Poisson process is frequently used to model arrivals to a system. Both of these distributions have the memoryless property, which means that the time between two arrivals is not dependent on the previous arrival. The input for the negative exponential distribution in PlantSimulation is the mean time between events. To determine the mean time between events, we use the average arrivals per day and the number of seconds from opening to closing time, being 32,400 seconds. To calculate the input parameter for the distribution we divide the time by the average number of arrivals. The used parameters can be found in Appendix D, Table D-1.

In Figure 3-6 the distribution of vehicles entering and leaving the terrain is shown. From the incoming vehicles, 30% is classified as car, 10% is classified as light truck, and 60% is classified as truck. On the outgoing side, we clearly see that most of the materials leave per truckload. According to the data classification, a small amount of materials leaves the terrain in a class B or C1 vehicle; this can be seen as a data error, since the company indicates that all materials leave per truck. Examining the data shows that these misclassifications are caused by missing weights in the registration. From this point on we classify all outgoing vehicles as a truck.

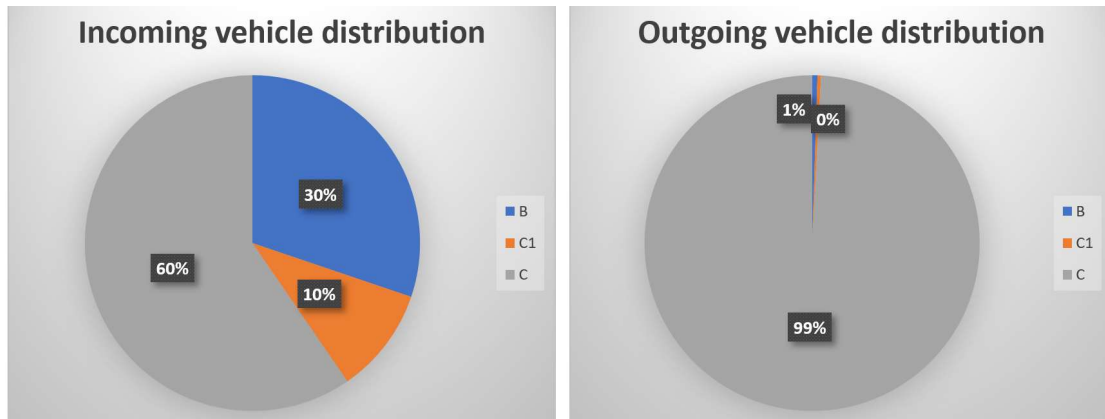


Figure 3-6 Distribution of incoming and outgoing vehicles

### 3.2.3 Material weight per vehicle class

In this section we determine the weight distributions per material and vehicle type. The loading weights of the vehicles are determined based on the weighbridge data over 2019. For each of the vehicle and material class the product weights are selected and used as an input to fit a continuous distribution, using the “reliability” Python library (Reid M. , 2020). Appendix D provides more background on the determination of each of the performed fits. Reliability fits more types of distributions than PlantSimulation can handle, we choose the (Chwif, Barretto, & Moscato, 1998) best fitting distribution that can be applied in PlantSimulation. The library allows to fit a range of continuous distributions, of which we can apply the Weibull, Gamma, Exponential, Lognormal and Normal distribution in PlantSimulation. The resulting distributions and parameters can be found in Appendix D, Table D-2. For each of the vehicles types, a continuous distribution is found.

### 3.2.4 Time spent on the location based on weighbridge data

In this section we discuss the times spent by different vehicles and material groups on the terrain. The time spent on the terrain is an important KPI. Incoming vehicles benefit from short lead times since it leaves time for other jobs. Van Gerrevink benefits by short processing times, since it creates the opportunity to service more clients in the same amount of time, increasing possible throughput and reducing work pressure. It also reduces the expected number of vehicles on the terrain at the same time. Table 3-6 and Table 3-7 show average, minimal and maximal waiting times for the different vehicle classes. These results are based on registrations from the weighbridge. The data on processing times is “polluted” by manual inputs, which are not representational for the actual times. It also happens that vehicles unload at the yard when the weighbridge is already closed, when this happens, the data is processed the next day. For data points with a processing time of zero or one minute, it is likely that it is a manual input given the short stay period. Data with these low processing times and which are marked as manual input are excluded from the time calculations since correctness cannot be verified. On the high range we exclude data with a processing time of over nine hours, since this is the maximal time a vehicle can be present on a given day.

Table 3-6 Time table incoming vehicles (2019) \*indexed

(HH):MM:SS	B				C				C1			
	Min	Avg.	Max	St. dev.	Min	Avg.	Max	St. dev.	Min	Avg.	Max	St. dev.
Residual	8:47	16:36	9:28	18:15	5:51	7:28	5:39	7:22	11:43	18:46	6:33	17:58
Ferro-metals	5:51	12:16	8:15	21:29	5:51	11:59	7:42	8:54	8:47	14:52	3:28	22:10
Glass	11:43	19:12	11:43	-	5:51	11:24	11:51	13:00	20:30	22:46	18:16	17:20
Wood	11:43	6:35	7:34	17:20	5:51	20:23	5:25	7:53	14:39	19:30	18:16	6:51
Plastics	8:44	22:55	19:23	15:08	5:51	5:47	5:36	21:43	8:47	23:33	7:45	13:14
Non-ferro Metals	5:51	7:58	7:04	5:59	5:51	15:42	7:45	17:48	5:51	7:25	23:00	3:55
Paper	8:47	20:50	7:16	6:07	5:51	1:33	11:10	4:47	8:47	8:40	4:10	0:07
WEEE	5:51	16:20	6:33	20:27	5:51	21:10	5:19	3:39	8:47	14:52	3:28	22:10

Table 3-7 Time table outgoing vehicles (2019) \*indexed

(HH):MM:SS	C			
	Min	Avg.	Max	St. dev.
Residual	5:51	18:30	13:31	8:05
Ferro-metals	14:39	23:22	6:09	0:17
Glass	8:13	23:42	22:19	15:28
Wood	8:47	1:37	8:56	7:25
Plastics	14:39	10:44	4:17	16:42
Non-ferro Metals	5:51	6:02	13:22	6:28
Paper	5:51	9:40	11:31	6:40
WEEE	14:39	0:39	8:55	11:53

### 3.2.5 Machine overview

In this section the different machines are discussed. To handle all logistical movements on the terrain the company operates a large variety of machines. Most of the internal transportation is done by forklifts, which are limited to a speed of 15 kilometers per hour. The forklifts are supported by a wheel loader and cranes. The wheel loader is used to handle and move loose materials over larger distances. The cranes are used at multiple locations. The largest crane is fitted with an polyp grab and mainly used at the scrap yard to handle metals, it can also be used to load containers at the wood and waste departments. Furthermore, there are three cranes fitted with a sorting grab. One is used to feed the HBC125 bale press and sort paper, the largest one is used in multiple departments to sort materials and load containers, and the smallest one is used as a backup when needed. Cranes are mostly used in the same department and do not drive a lot around on the terrain. In order to gain more knowledge on the usage of the forklifts, a GPS-tracker is used to monitor the locations of the forklifts, details on this are discussed in Section 3.2.6.

The impact of relocating departments on the operating cost of the cranes can be seen as low, since they do not move much between departments. The cost of running the wheel loader can be impacted by the distance between departments as it is used to move loose materials and implemented at different locations. The largest savings can be generated from the operation of forklifts, since these drive large distances between most of the departments. It would make sense to place departments with many forklift movements close together.

### 3.2.6 Gathering new data

In the following section we discuss the methods used to generate data about the current situation. The gathering of data is an important step towards the development of a discrete event simulation model. Data is needed to create, verify and validate the simulation model that is used to evaluate the different layout options. First, a source of data is needed to run all processes in the model. Next, performance data from the model is compared to real data to validate modelling results.

Observations to determine:

- Time between arriving on the terrain and entering the weighbridge
- Time between finishing unloading and entering the weighbridge
- Time spent on the weighbridge first time
- Time spent on the weighbridge before departure
- Time spent unloading at the outside paper bunker
- Time spent by the crane to load the paper container at the outside paper bunker
- Time spent by trucks at the scrap department

This data is used to run and validate the model.

#### *Processing times*

Clocking times and registering movements on location is an important step in understanding the movements and times spent on the terrain. Certain processing times cannot be derived from existing

data, but are important to understand the processes and determine performance. These times are measured using a stopwatch and stored in an excel file. Times can be measured real time, but can also be taken from surveillance footage. Time measurements are taken for different locations, to determine the input for the simulation model. The processing times in Table 3-8 are partly based on a previous research performed at the company (Straathof, 2018). The origin of the data will be briefly explained.

Table 3-8 Location processing times \*Removed for publication

Location	Distribution	Parameters
Weighbridge	Gamma	[ $\alpha$ = ; $\beta$ = ]
Wood loading	Gamma	[ $\alpha$ = ; $\beta$ = ]
Wood unloading	Gamma	[ $\alpha$ = ; $\beta$ = ]
Plastics loading	Normal	[ $\mu$ = ; $\sigma$ = ]
Plastics unloading	Gamma	[ $\alpha$ = ; $\beta$ = ]
Non-ferro loading	Normal	[ $\mu$ = ; $\sigma$ = ]
Non-ferro unloading	Gamma	[ $\alpha$ = ; $\beta$ = ]
Ferro loading	Normal	[ $\mu$ = ; $\sigma$ = ]
Ferro unloading	Normal	[ $\mu$ = ; $\sigma$ = ]
Archive	Gamma	[ $\alpha$ = ; $\beta$ = ]
Paper unloading	Normal	[ $\mu$ = ; $\sigma$ = ]
Loading bridge	Normal	[ $\mu$ = ; $\sigma$ = ]
Loading area paper	Normal	[ $\mu$ = ; $\sigma$ = ]
Metal purchasing	Normal	[ $\mu$ = ; $\sigma$ = ]

There are two methods used to determine the data distributions, weighbridge data and observations. For the following locations, observations are used to determine the processing times:

- Weighbridge
- Metal purchasing
- Paper unloading
- Loading bridge
- Loading area

For the other locations, data from the weighbridge registrations is used to determine the corresponding distributions. The downfall of using the distributions is that these times include the driving, waiting and manoeuvring times of the vehicles between incoming and outgoing weight registrations. This should not be a problem given that we use the same processing times in all situations and look for the difference in waiting times between layouts. The processing time will have a greater impact on the total time than in reality. These distributions can be tweaked to increase the reliability of the model in terms to total processing time.

*Data from the baler*

The HBC125 baler stores statistics on the number of bales produced in the last 30 days, and in the last twelve months. This data is collected from the machine and processed to gain insight in the connection between incoming materials registered at the weighbridge and the number of bales produced.

A comparison between baler data and weighbridge data can be found in Table 3-9. The data from the HBC125 is taken directly from the baler computer; the data from the HBC80 is taken from the bale counter registration. There is a difference between the expected bale weight and the weight registered on the weighbridge. The expected bale weight also includes bales that are reworked, and thus registered twice. Furthermore, the weight of the bales differs slightly and not all materials lead to the same bale weight.

Table 3-9 Paper bale and weight data \* indexed

Month	Number of bales HBC 125	Number of bales HBC 80	Expected total bale weight [kg]	Weighbridge in [kg]	Weighbridge out [kg]
May '19	8,561	2,145	9,795,137	11,157,953	10,415,037
June '19	10,633	1,767	11,559,729	9,521,656	8,884,551
July '19	12,907	2,936	14,565,689	11,563,002	11,499,019
August '19	10,319	1,954	11,380,633	9,662,018	12,500,816
September '19	11,483	2,291	12,742,204	10,352,001	10,504,021
October '19	11,448	2,288	12,705,945	10,957,822	10,418,728
November '19	11,146	2,300	12,419,611	10,518,905	10,133,815
December '19	11,503	2,602	12,971,843	9,574,212	7,852,195
January '20	11,600	2,060	12,700,232	10,545,460	9,475,444
February '20	11,026	2,236	12,258,974	9,068,860	10,479,204
March '20	11,574	2,491	12,965,250	10,761,474	12,565,422
April '20	10,774	1,825	11,736,408	8,098,854	8,776,112
Total	132,972	26,894	147,801,653	121,782,215	123,504,364

### GPS

For the collection of data about the movement of forklifts on the terrain, a GPS tracking app on a mobile phone (Samsung Galaxy S5 G900F) is used. The device makes use of the following GPs protocols: A-GPS, GLONASS, BDS. Data is collected on different days, times and forklifts. The collected data has advantages and flaws. The data can be used to retrace visited locations and provide insight in frequently used routes and locations. With the data points a centre of gravity analysis and spaghetti diagram can be made. Drawbacks of the data is that it is not fully accurate, the data sometimes shows outliers and unreachable locations. Data is filtered from data points that create excessive speeds; this results in a smoother figure. The location of the device tends to jump in a small radius when the device is actually still, this results in low-speed noise. The useful amount of data ended up being small due to a combination of problems with the tracker and less time on location due to corona. In order to gain more information about the forklifts it would be good to gather data over a longer period of time and on multiple forklifts at the same time. It is possible to review the collected data.

Using the tool "GPXSee" we estimated the location visited by the forklift on the datapoints. The estimated locations are listed. Using this list, the number of movements between two locations can be counted and shown using excel. Figure 3-7 shows different routes from different forklifts. These images give an idea about the movements of different forklifts over the terrain. The forklifts are generally operated by the same person and departments, so the visited locations do not differ much from day to day.

Figure 3-7 shows four different forklift traces. In the upper left picture, the route of the large bale clamp forklift on 06-04-2020 is depicted. This forklift is the main mover of bales from the balers to storage locations and is used to load outgoing trailers with bales. After reviewing the data, an estimation of 50 trips from the baler to storage locations is determined, which corresponds to roughly 100 bales. Looking at the incoming data for the same date, we see that a total of X,X kg of paper is delivered to the baler, which should translate to 148 bales. From the baler computer, we found that a total of 151 bales are registered that day. If we compare the data retrieved from the GPS-tracker, weighbridge data and baler computer, we see that the weighbridge data and baler computer have a good match and the estimations from the GPS-tracker are far off. Given the low accuracy we only keep the GPS data to give an impression of usage and base the results on data from the weighbridge and baler. The upper left picture in Figure 3-7 shows the movements of the forklift used at the metal purchasing department. This forklift is used to move metals from the purchasing department to the scrapyards and the metal storage, it is also used to perform other jobs when time is available. The two bottom pictures in Figure 3-7 show two of the all-round forklifts which are used to move materials on the terrain and load and unload vehicles.

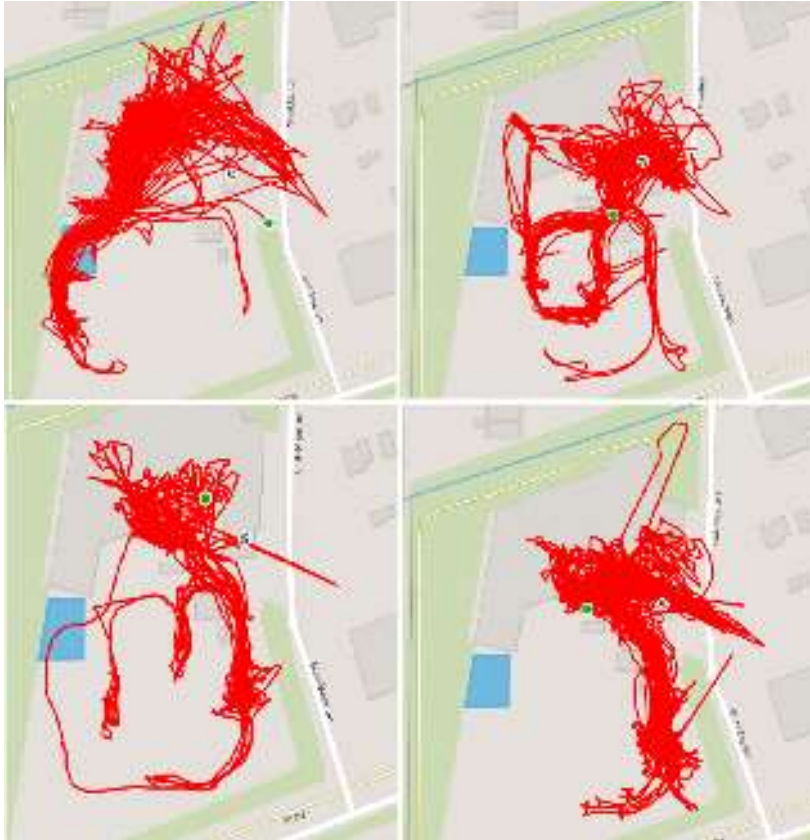


Figure 3-7 Different forklift tracings

### 3.2.7 Flow of materials and vehicles

This section elaborates on the different material flows, vehicle movements and processing methods. We discuss 9 flowcharts in this section. First, the flow of vehicles not belonging to internal transportation on the terrain is discussed, followed by the flows of all main material types: residual waste, glass, wood, plastics, metals, paper, WEEE-material. The weights and numbers in this section are based on company data from the year 2019. The flow of vehicles is used to determine the number of movements between departments made for the incoming and outgoing movements. The material flowcharts are used to determine the movements made by internal transportation means.

#### *Vehicle flow*

The flow of vehicles on the terrain can be divided into two categories: vehicles belonging to internal transportation and vehicles not belonging to internal transportation. Internal transportation is used to move materials between departments and processes and enables the company to function. The internal logistics are handled by forklifts, cranes, a wheel loader and a truck, as discussed in Section 3.2.5. There are also vehicles on the terrain not belonging to the internal logistics. These vehicles are used to move materials from and to the yard, we classified these vehicles as “car”, “light truck” and “truck”. The movements of the vehicles not belonging to internal transportation are relatively simple. The flow of vehicles not belonging to internal transportation is visualized in Figure 3-8, these movements can be linked to data from the weighbridge to get an understanding of the amount of vehicle movements between locations.

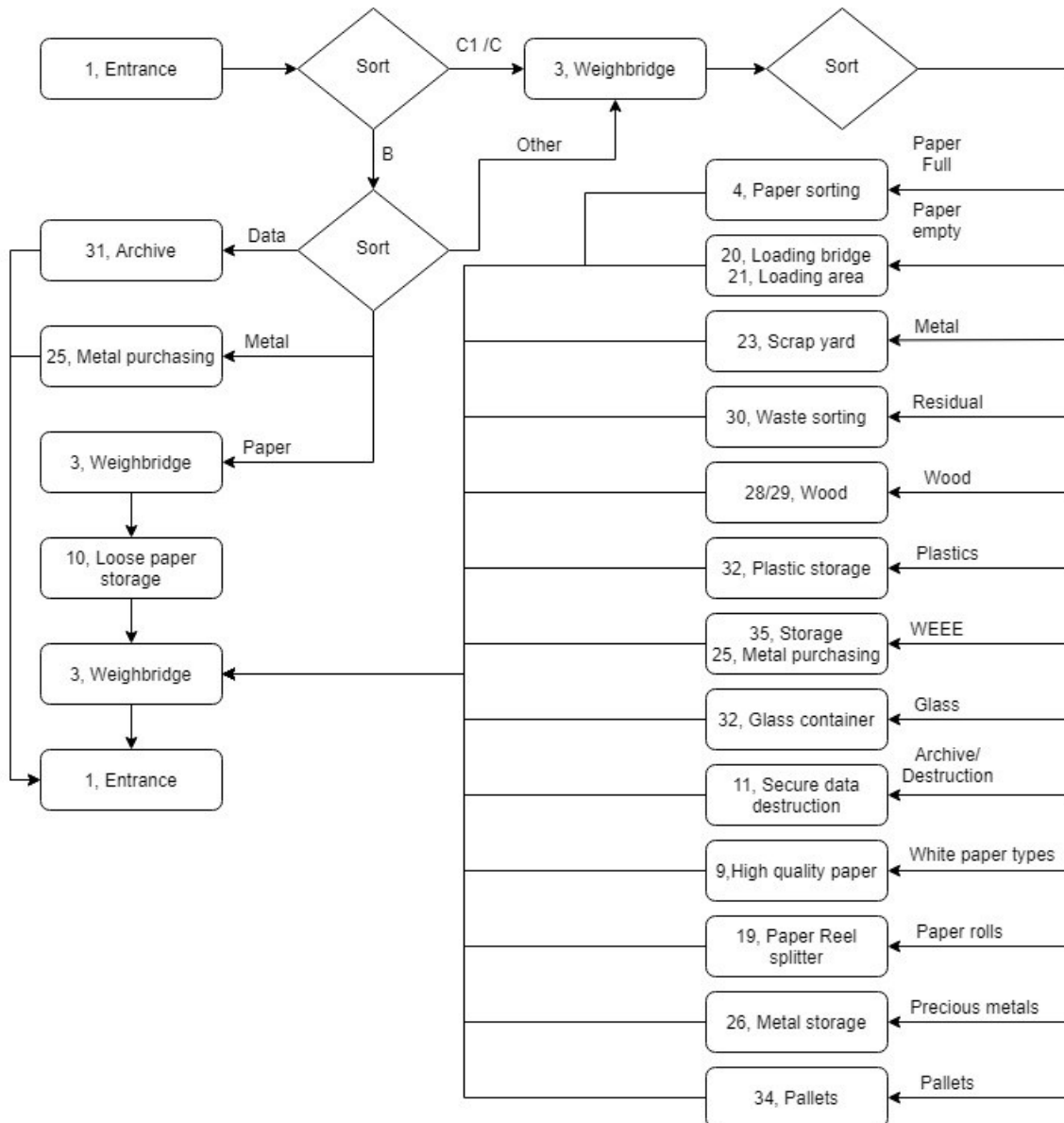


Figure 3-8 Flowchart vehicles road transport

### Residual waste flow

The term residual waste flow is used to describe the flow of materials registered as waste. This also includes some materials like construction waste, which is not processed. The most important are residual waste, which is sorted, and glass fleece, which is cut. In Figure 3-9, the general flow of materials in this class is presented. The incoming waste flow is sorted and divided into residual waste, glass fleece, pallets, wood and scrap. Residual waste is loaded into containers and collected by a waste company. Pallets, wood and metal are extracted during this sorting process, exact amount are not traceable and left out of the flowcharts. Glass fleece is processed at the reel splitter, incoming rolls are cut and loaded into containers. Glass fleece is brought in on rolls, these rolls are cut at the reel splitter and the processed materials are loaded into a container. Materials for destruction are also registered as waste, these materials are processed at the secure data destruction location and stored until sold.

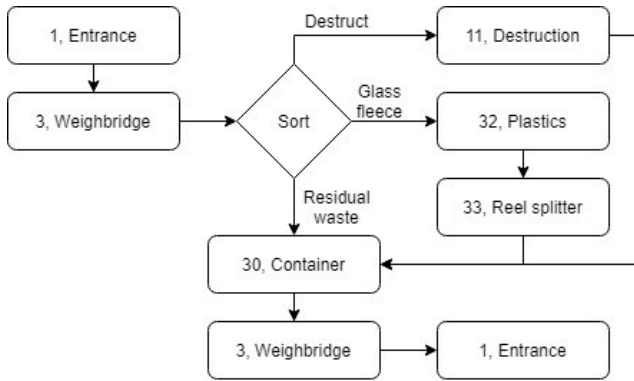


Figure 3-9 Flowchart waste

### Glass

Glass material is collected into a small container on the yard. When the container is full, it is emptied by another company. Glass is not processed by Van Gerrevink and not actively collected. Glass flows on the terrain as shown in Figure 3-10. This flow is omitted in the remainder of the report.



Figure 3-10 Flowchart glass

### Wood

Wood is sorted into two types, A-wood and B-wood, which are stored in adjacent locations. Wood is collected at the yard and also comes from sorting processes. Pallets are put aside and stored separately. Wood is loaded into containers, which are collected by another company when they are full. Material handling in the yard is mainly done by cranes, pallets can best be moved by forklifts. Material flows from sorting are excluded since exact data is not available. The general material flow can be seen in Figure 3-11.

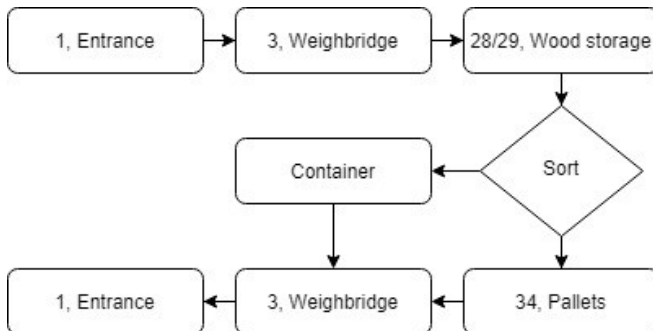


Figure 3-11 Flowchart wood

### Plastics

Plastics are collected at the yard and sorted. The different types are stored at different adjacent bunkers. All plastics enter the terrain through the entrance and the weighbridge, and are stored at the plastic department. The different types are sorted and collected in a container. When full, the containers are taken away.

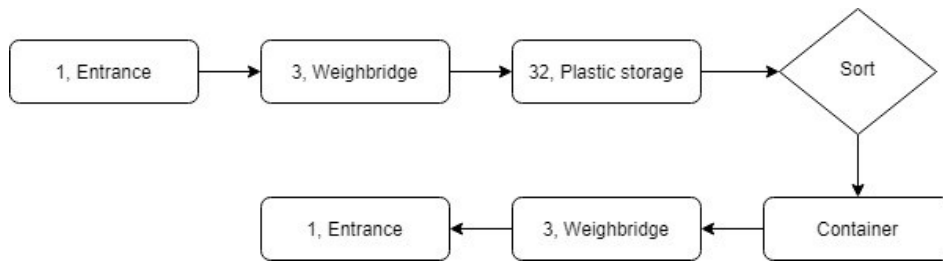


Figure 3-12 Flowchart plastic

### Metals

Trading and processing metals is another important part of the business of Van Gerrevink. There are many different flows associated with the flows of metals. Looking at the movements of type B vehicles with metal, it is found that in 2019 55% is routed to the metal purchasing department and 45% is routed via the weighbridge to the iron yard. In the metal purchasing department, the metals are sorted into different containers, when a container is full, it is taken to the metal storage. At the scrap yard, different metals are stored. Incoming materials are placed at the correct locations, large pieces of metal are cut by the scrap shear. Metals that are sold are loaded into containers and exit through the weighbridge and entrance. For simplification reasons we assume that all B-type vehicles go to the metal purchasing department.

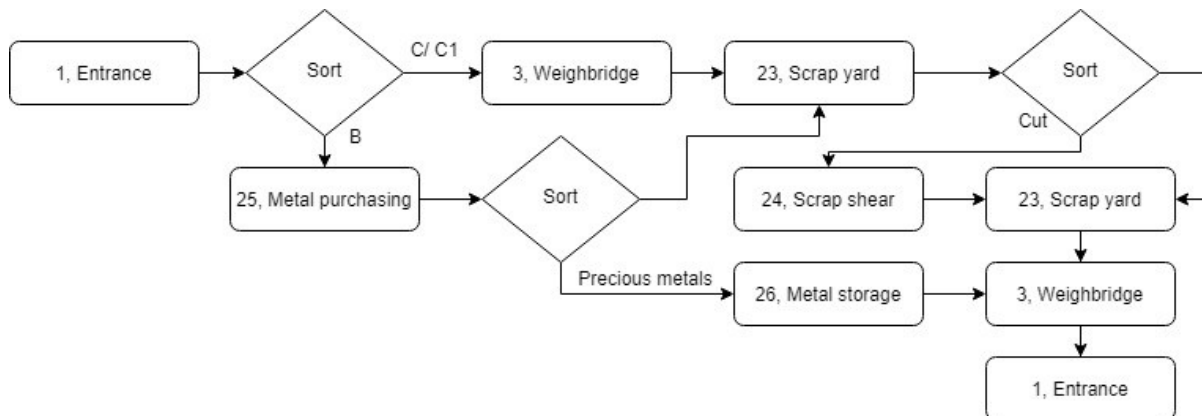


Figure 3-13 Flowchart metals

### Paper

Paper is one of the most important materials processed by Van Gerrevink, as discussed in Section 3.2.1. For this material there is a different process for trucks and individuals. Individuals are sent to the archive intake or paper bunker at the back of the terrain. This bunker is emptied by loading the paper into a container and driving it to the sorting area, creating additional workload. Trucks are sorted based on their load. Archive material is unloaded at the secure data destruction. High quality white paper is stored for shredding. Rolls are cut before they can be baled. All other types of paper are unloaded at the paper sorting location where the crane operator sorts the material and feeds it to the baler. At the back of the balers, a forklift is used to store the bales. Bales are sorted by the forklift driver based on type and quality, this determines where they are stored. Empty trucks are loaded by a forklift, the loading location depends on the type of truck.

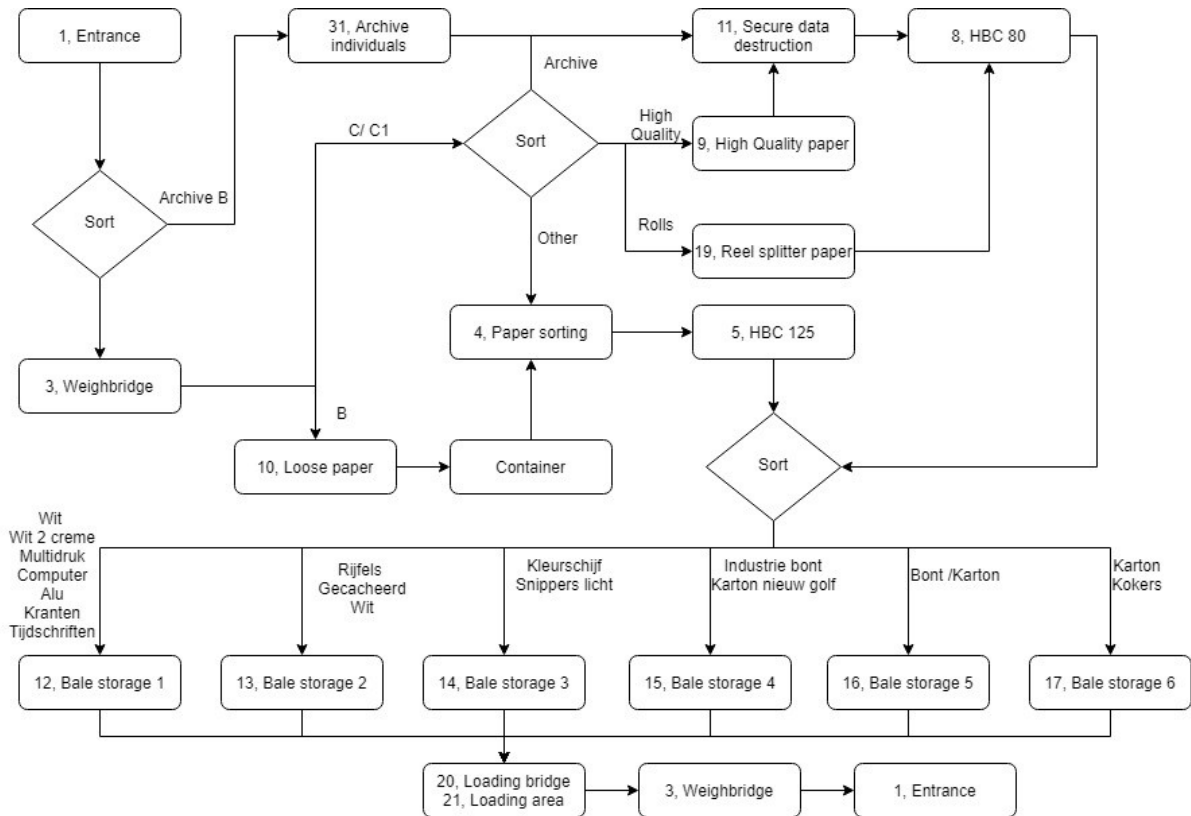


Figure 3-14 Flowchart paper

### WEEE

There are many types of WEEE-waste defined, which are processed by Van Gerrevink. Electrical equipment is taken apart so that the components and precious metals can be recycled.

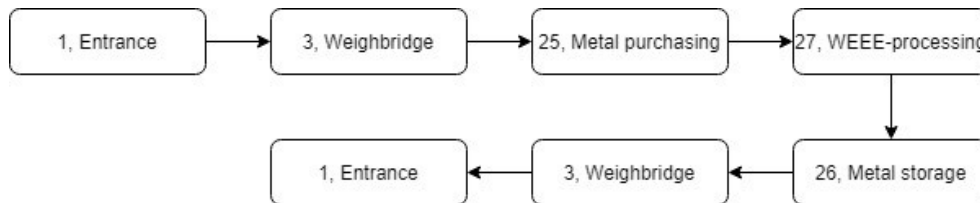


Figure 3-15 Flowchart WEEE

### Internal transportation

This section is specifically aimed at the internal transportation means, which include forklifts, cranes and a wheel loader. Internal transportation is used to move the materials from the location where external vehicles unload to the location where external vehicles are loaded. The movements of internal transportation means are an important aspect in the total number of movements on the terrain and cannot be disregarded. Movements of internal transportation vehicles are harder to determine and quantify. Using observations, GPS and data, estimates about movements can be made. GPS data can reveal the movements of vehicles to a certain degree as discussed in Section 3.2.6. Internal transportation machinery does not follow a fixed route, but they can often be linked to certain departments or movements. Forklifts are used to move all kinds of materials between all different departments. Their versatility makes it hard to determine exact movements. Based on the flow of materials, an estimation of forklift movements can be made. The movements between departments that do not have a direct material flow are harder to determine. Cranes move around the terrain to maintain storage locations and load external vehicles. The wheel loader is mainly used to tidy storage locations and move small amounts of paper.

### 3.2.8 Relationship chart

Relationship charts are used to analyse the relationships between departments. The relation between each pair of departments is characterized by a letter representing the closeness rating and a number to represent the reason of why the proximity rating is given. There are many different materials handled on the terrain, some share resources and others have special equipment requirements. The large amount of departments that must be accounted for leads to many combinations of flow between departments. To quantify the relations between departments, the flowcharts and weighbridge data are used. Based on the flows of materials in the flowcharts, the registered number of vehicles can be linked to a department relationship. Internal movements are determined based on weight. The processed weight per material flow is known, with this we can estimate the needed amount of trips by a forklift to move the goods. Additionally, relations between departments that involve movements of people are added. For the locations where internal transportation is used to move goods, we use the values given in Table 3-10 to transfer from weight to number of trips, if the number of trips is not known from existing data. The resulting number of movements can be found in Appendix C, Table C-1, the departments where no connections are found are removed from the table. The relationship chart provides a clear overview of the important connections. Proximity rating values and colours are based on “Systematic layout planning”, (Muther & Hales, 2015), reasons are adapted to suit the needs of the situation and all can be found in Table 3-11. The complete relationship chart can be seen in Figure 3-16. Table 3-11 also lists the cut-off percentage that is used to determine the classification value for a relation, e.g., value A is assigned if the number of movements between two departments is more than 8% of the total amount of registered movements. The table also provides a list with used codes of why a classification is assigned.

Table 3-10 Unit load assumptions

From	To	Unit load	Transporter	From	To	Unit load	Transporter
11	30	1,500	Forklift	5	13	1,900	Forklift
32	33	750	Forklift	5	14	1,900	Forklift
33	30	1,000	Forklift	5	15	1,900	Forklift
25	23	150	Forklift	5	16	1,900	Forklift
25	26	500	Forklift	5	17	1,900	Forklift
23	24	750	Crane	8	14	1,350	Forklift
24	24	750	Crane	12	20/21	1,900	Forklift
23	23	750	Crane	13	20/21	1,900	Forklift
31	11	250	Container	14	20/21	1,350	Forklift
9	11	750	Wheel loader	15	20/21	1,900	Forklift
19	8	500	Forklift	16	20/21	1,900	Forklift
10	4	5,000	Truck	17	20/21	1,900	Forklift
4	5	1,000	Crane	25	27	1,000	Forklift
5	12	1,900	Forklift	27	26	1,000	Forklift

Table 3-11 Proximity values and codes

Value	Proximity	Color	Percentage lower bound	Times assigned	Code	Reason
A	Absolutely Necessary	Red	8	4	1	Flow of materials
E	Especially important	Orange	2.5	12	2	Flow of people
I	Important	Green	1	34	3	Convenience
O	Ordinary Closeness OK	Blue	0	14	4	Common type of space
U	Unimportant	White	-	1,418	5	Common type of material
X	Not Desirable	Brown	-	-	6	Nuisance

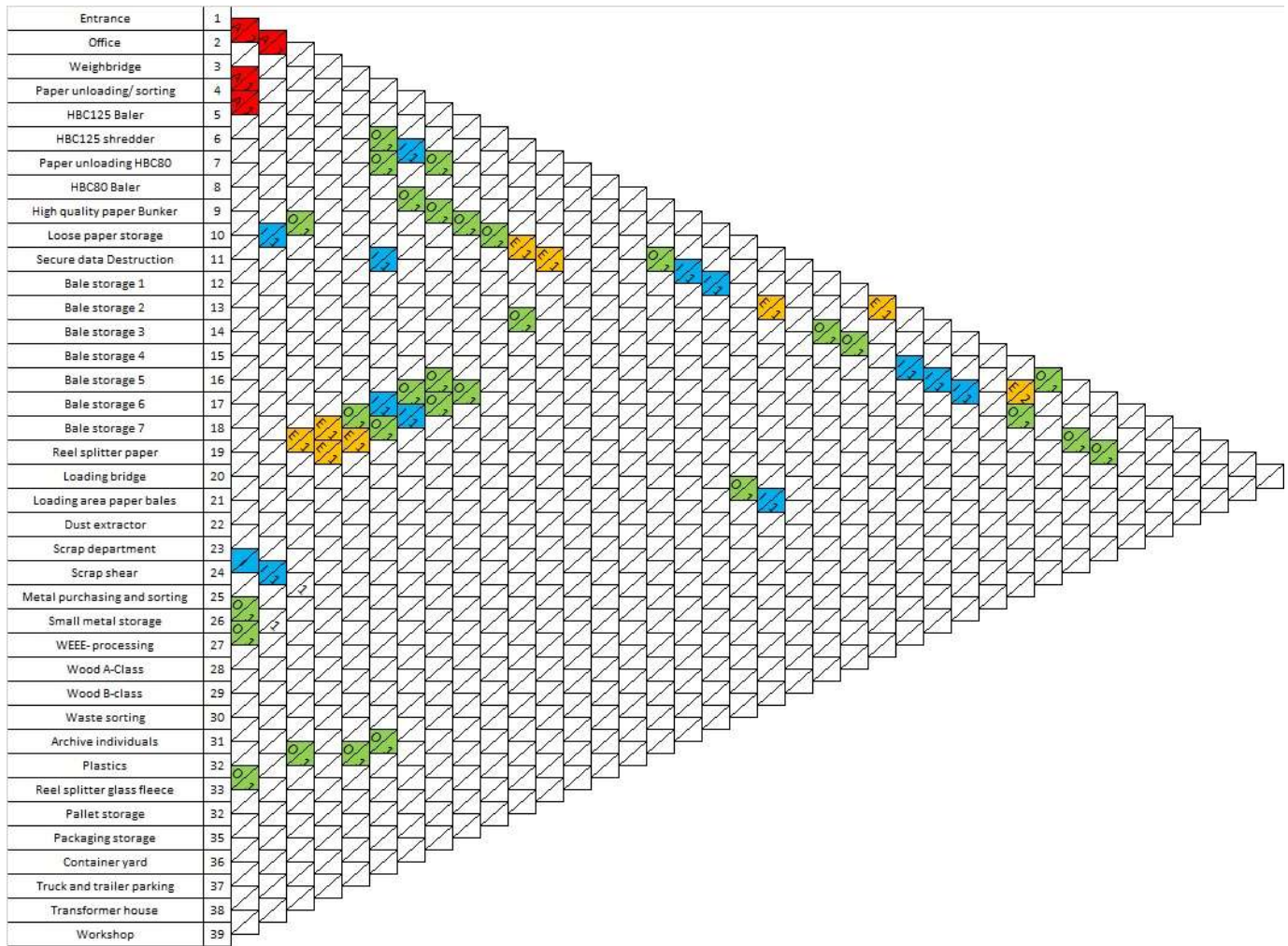


Figure 3-16 Activity relationship chart

### 3.2.9 Conclusion

Different methods of data collection and processing are discussed in this section. The division of materials entering and leaving the terrain is shown based on material type and the movements are linked to the different types of vehicles. Paper and metal are the most important materials for the company. It is found that over sixty percent of external vehicle movements is caused by trucks. The average times spent on the terrain to unload lie between eight and nineteen minutes. For the outgoing vehicles the averages vary between sixteen and fifty-two minutes. The distributions for interarrival times and load weights are determines for each vehicle type and material. The different machines used for internal transportation are discussed, this includes forklifts, cranes and a wheel loader. Existing data from the weighbridge is combined with data originating from GPS-tracking, observing and clocking, and data from the baler. In order to visualize and trace the movements on the terrain, flowcharts are used to provide the links between departments. One flowchart is dedicated to the movements on vehicles entering the terrain for loading and unloading, for each of the main materials a flowchart is used to link the movements on internal transportation means. From the flowcharts, a relationship chart is made. The relationship chart is used to visualize the importance of the connection.

### 3.3 Key performance indicators

In this section the selection of key performance indicators (KPIs) is discussed. For the selection of KPIs we keep in mind to select measurements we can influence by adapting the layout. An example of this would be the distance driven per day, since we can minimize this by shortening high frequency routes. The use of for instance number of bales produced per year is a less applicable KPI for the problem, although it being an important KPI for the company, it is dependent on the amount of material delivered to the company and not influenced by the layout of the terrain. In this report we focus on the KPIs that can be influenced by the layout:

- Staff utilization
- Distance driven by external vehicles
- Distance driven by forklifts
- Waiting times
- Number of trucks at the location at the same time
- Time spent on the terrain by a truck on each location

Staff utilization is an important KPI for the company. The workload should not be too high or too low, this can both lead to unsatisfied staff members. High utilization creates more pressure on staff, where low utilization is a waste of money and energy. The distance driven on the terrain is a good KPI to measure the effectiveness of the layouts. Layouts that require large distances to be covered will have higher transportation costs. More driving means more crossing traffic and increases waiting. The total distance driven is also an indicator of cost. The total distance driven can be estimated by multiplying the average number of trips between departments with the distance between these departments. With the simulation model we can compare covered distances of vehicles. Waiting times are a very important factor for all people involved. In transportation, standing still waiting means loss of revenue. Reducing waiting times and increasing throughput will benefit the satisfaction of people and other companies. The number of trucks/ vehicles on the terrain can be seen as a measure of how busy it is. It is to be expected that an increase in the number of vehicles leads to an increase of utilization and waiting times. With the relationship diagram, an estimation of the total distance driven by the forklifts can be given. The total distance can be used to make a cost calculation for internal transportation. The total time spent on the location by external transportation vehicles is an important KPI, the aim is to service customers as fast and good as possible.

A discrete event simulation model is used to evaluate these KPIs for multiple layout options. By registering the times at which vehicles pass certain locations and the distance driven, we can use these measurements to compare different layouts. Results from this study can be found in Chapter 6.

### 3.4 Conclusion

In this chapter, the current situation at Van Gerrevink is discussed. We defined key performance indicators that can be used to evaluate different layout options. The current situation is analysed and data is used to provide distributions and reference points for the evaluation. The flow of materials and vehicles on the terrain is documented. There are many material types being handled on the terrain and materials are moved all over the terrain. Distributions are determined with the evaluation model in mind and for each separated vehicle type and material the data is analysed. Data inputs regarding handling times and movements are collected and documented. Initially the locations around the weighbridge, entrance and paper unloading are marked as bottleneck locations because of their high vehicle throughput.

## 4. Defining new layout options

In this chapter we discuss the creation of new layouts. The chapter can be divided into two main sections: the green field solution, and adaptation of the current layout. First we define our choice of approach in Section 4.1. In Section 4.2 we present our construction of the greenfield layout. In Section 4.3 we propose different adaptations of the current layout.

### 4.1 Choice of approach

In this section we discuss the choice of approach for the creation of new layouts. First, the general approach is discussed, which is later specified for each of the situations. Second, the system of creating a green field layout is discussed, followed by a section specifying the steps necessary to create alternative layouts based on the current situation.

#### 4.1.1 General approach

A distinction is made between a green field solution and solutions based on the current situation. For both problems we aim to apply comparable methods. Systematic layout planning can be adapted to suit the needs of both problems. The systematic can be applied by hand and restrictions and wishes can easily be incorporated. Systematic layout planning is discussed by Muther and Hales (2015) and in Section 2.2.1. In this method, the connections between departments are ranked and departments are positioned in a manner that minimizes the length of high ranked relations. From all these rankings, a list is made that shows the order of importance of the connections, this list can be used to make the layout plan. In this part of the process, dimensions of the departments are disregarded. The goal is to fit the departments with the most interactions together.

#### 4.1.2 Creating a new layout based on an empty yard, greenfield solution

In this part the creation of a green field solution is discussed. In this situation we start with an empty perimeter and place all departments. In this situation we start with an empty layout. The first step is to add all departments with an A-type connection, and rank them on number of A-type connections. The department with the most connections is placed first. We aim to spread the department that are not connected, so there is space to connect other departments. When all A-type connections are placed on the terrain, the departments with an E-type connection are added. Relocation of departments already in the layout might be necessary to reduce crossing of flow lines. Restrictions on departments should be kept in mind when placing the departments. This process is continued until all departments are added to the layout. During the creation of the layout, we aim to keep a direct flow of goods, with minimal alteration in direction. Furthermore, we aim to keep departments that process the same type of vehicles or materials clustered and as much in-line as possible. During the creation of the block-layout, we do not take the actual shape of the location into consideration. When the SLP-method is finished and an initial layout is created, the CRAFT heuristic is used with the aim of finding a better solution. The block-layout is the basis which is finetuned to meet the requirements of the actual location. When the block-layout is finished, the size requirements are implemented and small adaptations to the initial layout might be necessary.

#### 4.1.3 Creating alternatives based on the current situation

For the creation of alternative layouts, we start with the current layout as a base. A distinction is made between departments that can be relocated relatively easy and departments that are more bound to their current location. During the design of alternatives, this must be accounted for. In this situation, we can apply systematic layout planning in a slightly modified manner. The locations that are fixed can be put into the diagram and the free to move departments can be included in the best fitting way. This approach allows to deal with all kinds of constraints and wishes. The next step is to apply the CRAFT heuristic which allows the swapping of equal size and neighbouring departments, with the limitation of the fixed departments. The fixation of department can decrease the amount of possible swaps, resulting in a low overall improvement.

## 4.2 Creation of the greenfield solution

This section is dedicated to the creation of a greenfield solution for the yard of Van Gerrevink. This means that there are no starting restrictions to the placement of departments, all departments can be placed on an empty field. To create a new layout we follow the procedure as explained in Section 4.1.2.

### 4.2.1 SLP initial solution

Since all departments are considered, we start by placing the departments with A-type connections in the layout. The first departments placed are: 1, 2, 3, 4, 5. A-relations are marked by four lines. Location 1 is the entrance and should be surrounded on at most three sides for road access. The aim is to keep a flowing line and comply with constraints when placing the departments. Figure 4-1 shows our placement of the A-type departments.

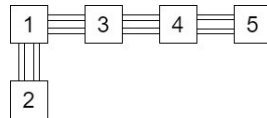


Figure 4-1 A-Type relations Greenfield

The next step is to add the E-type relations to the grid, satisfying as many relations as possible and keeping distances mostly equal. Departments 6, 7, 8, 16, 17, 20, 21, 23, 25 and 31 are added and relations are shown by triple lines. If placement is possible in multiple equally suitable locations, we select the placement based on what we expect to be best fitting with the next departments that are placed. The placement of the new departments is visible in Figure 4-2, the locations 7 and 8 have no connections to placed departments yet and are placed at the current bottom of the layout.

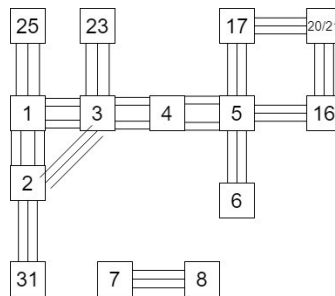


Figure 4-2 E-Type relations Greenfield

The placement of the E-type relations is followed by the I-type relations, which are denoted by double lines. The following departments are added 9, 10, 11, 14, 24, 28, 29, 30. Figure 4-3 show our placement of the new departments. Except department 9 and 11, all departments can be connected to existing locations. Departments are placed so that the spread is as large as possible. Departments 9 and 11 are placed at the top side next to department 24, since there is the most available space.

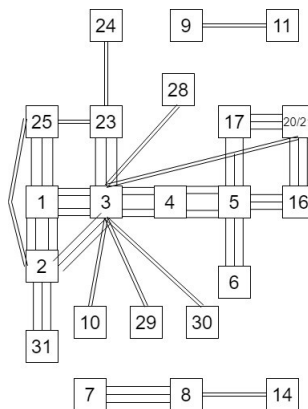


Figure 4-3 I-Type relations Greenfield

When all I-type relations are placed, the O-type relations are added. In this step, the following departments are added: 12, 13, 15, 19, 22, 26, 27, 32, 33, 34 and 35. First, the departments are placed close to the departments that they connect to as can be seen in Figure 4-4 (L). The second step is to move the departments in such a way that the amount of crossing lines and length is minimized. The final placement of the O-Type relations can be seen in Figure 4-4 (R).

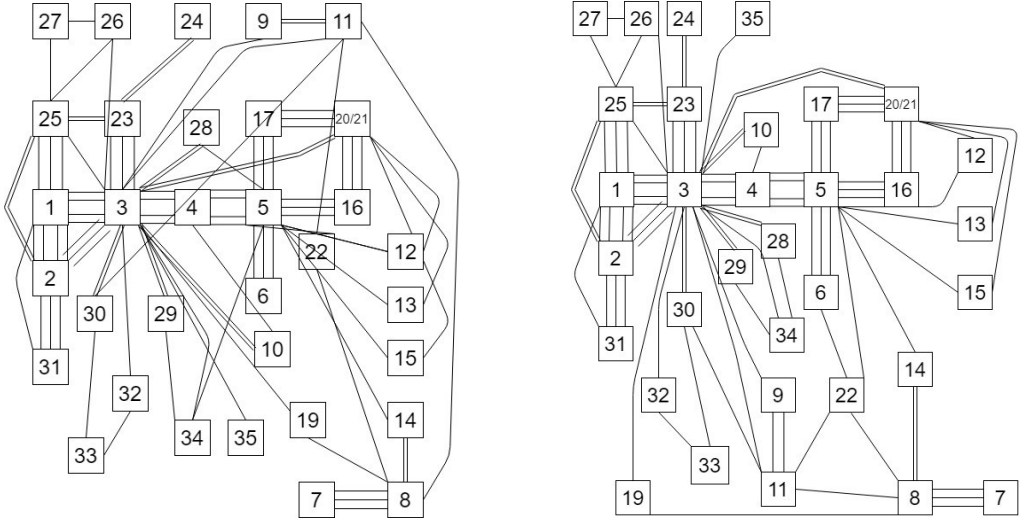


Figure 4-4 O-Type relations Greenfield (L), O-Type relations Greenfield rearranged (R)

The final step is to add the departments for which no direct flows are determined but still need to be on the yard. The following departments are added: 18, 36, 37, 38 and 39. We place these locations on the outside of the terrain where there is space available. The final placement of all departments in the greenfield layout is presented in Figure 4-5.

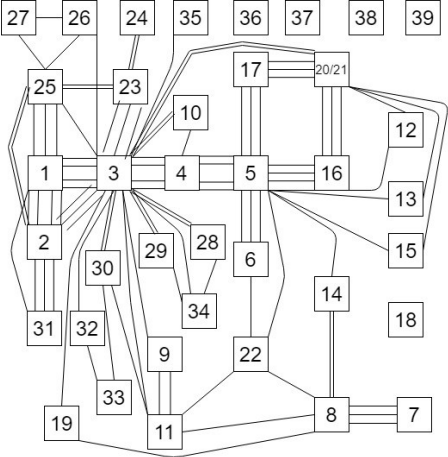


Figure 4-5 All departments added to the Greenfield layout

4.2.2 Craft improvement for greenfield solution

The block plan as shown in Figure 4-5 is translated into an initial solution that can be used in a CRAFT algorithm. The idea and methods behind CRAFT are discussed in Section 2.2.2. During the creation of the layout we explain the steps we take. To reduce the workload of performing CRAFT, we use an automated implementation in Excel where each cell equals a block. In the used CRAFT application, we have a field with a maximum size of 100x50 blocks. Each of the departments is assigned an amount of blocks that corresponds to its size. The total company area and department sizes are scaled to fit in the available amount of blocks. To match the CRAFT field with the company size (185x120 meters), we implemented a CRAFT field of 77x50 blocks. This means each block has a size of 2.4x2.4 meters. The required department sizes (Section 3.1.2) are used to assign a number of blocks. The original area

requirements exclude the needed driving area. Blocks are assigned based on the same size ratio as the required area, this means the departments in CRAFT are slightly larger than required. We use this additional space as driving space. The amount of blocks is determined by dividing the area requirement by 2.94 and rounding up the result.

We now know the amount of blocks that need to be assigned for each department. Using SLP, we determined where the departments are to be placed relatively to each other as can be seen in Figure 4-5. Based on these locations, we placed the required number of blocks per department in the allowed area of 77x50 blocks. The result of our block placement is shown in Figure 4-6, note that the layout is rotated 90 degrees counter clockwise.

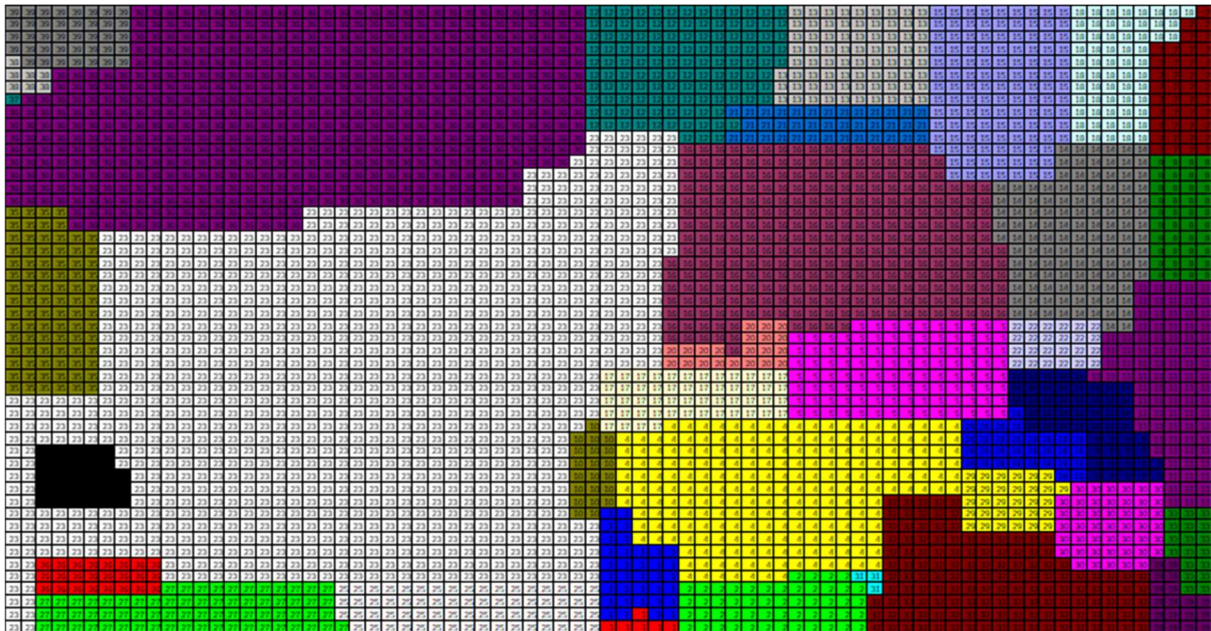


Figure 4-6 Greenfield CRAFT implementation

To determine the travel distances in the layouts, we consider two options: Euclidian distance and Manhattan distance. Euclidian distances are used when vehicles can travel in a straight line between department centroids. Manhattan distance is commonly used when vehicles can only travel parallel to the outlines of the layout. The layouts we evaluate have a mixture of Euclidian and Manhattan characteristics. We opt to use the Euclidian distance measurement multiplied by a factor to account for the fact that not all trips can be made in a straight line. For a small set of connections we used Google Maps to determine the distances between them. Table 4-1 shows our selection of departments with the real driving distance between them, the Euclidian distance and the corresponding factor. The factor is calculated by dividing the real travelled distance over the Euclidian distance. Based on the eight distance measurements listed in Table 4-1, the factor 1.23 is found and incorporated as the factor that increases the Euclidian distance.

Table 4-1 Distance factor determination

From	To	Real distance [m]	Euclidian Distance [m]	Factor
HBC125	Bale storage 16	165	135	1.22
Metal purchasing	Metal storage	116	98	1.18
Weighbridge	Wood storage	160	85	1.88
Metal purchasing	Scrap yard	88	82	1.07
Entrance	Weighbridge	45	45	1.00
Weighbridge	Paper unloading HBC125	76	71	1.07
Bale storage 12	Paper loading	93	81	1.15
Weighbridge	Waste sorting	94	75	1.25
Average factor				<b>1.23</b>

In this stage we have provided the CRAFT heuristic with an initial layout, the flows between departments, and a distance measure (Euclidian x 1.23). The CRAFT heuristic can make two kinds of swaps: equal sized departments, and adjacent departments. The program will make all possible swaps, determine which swap improves the objective function the most and select that as the new layout. This swapping and selecting is continued until there is no improvement found. The section follows is of the greedy kind and does not consider future options. When running CRAFT on the greenfield solution, we could not find a better configuration by swapping departments. Given that we provided CRAFT with an initial layout that we designed to be optimal for our criteria, we did not expect much room for improvement. Therefore, we decided to translate our greenfield solution from SLP into an applicable layout. We aimed to place the departments as close as possible to the placement in the CRAFT implementation. In Figure 4-7 we present our greenfield layout as an implementable layout. Departments are placed such that the available area is all in use and there is room for driving and manoeuvring.

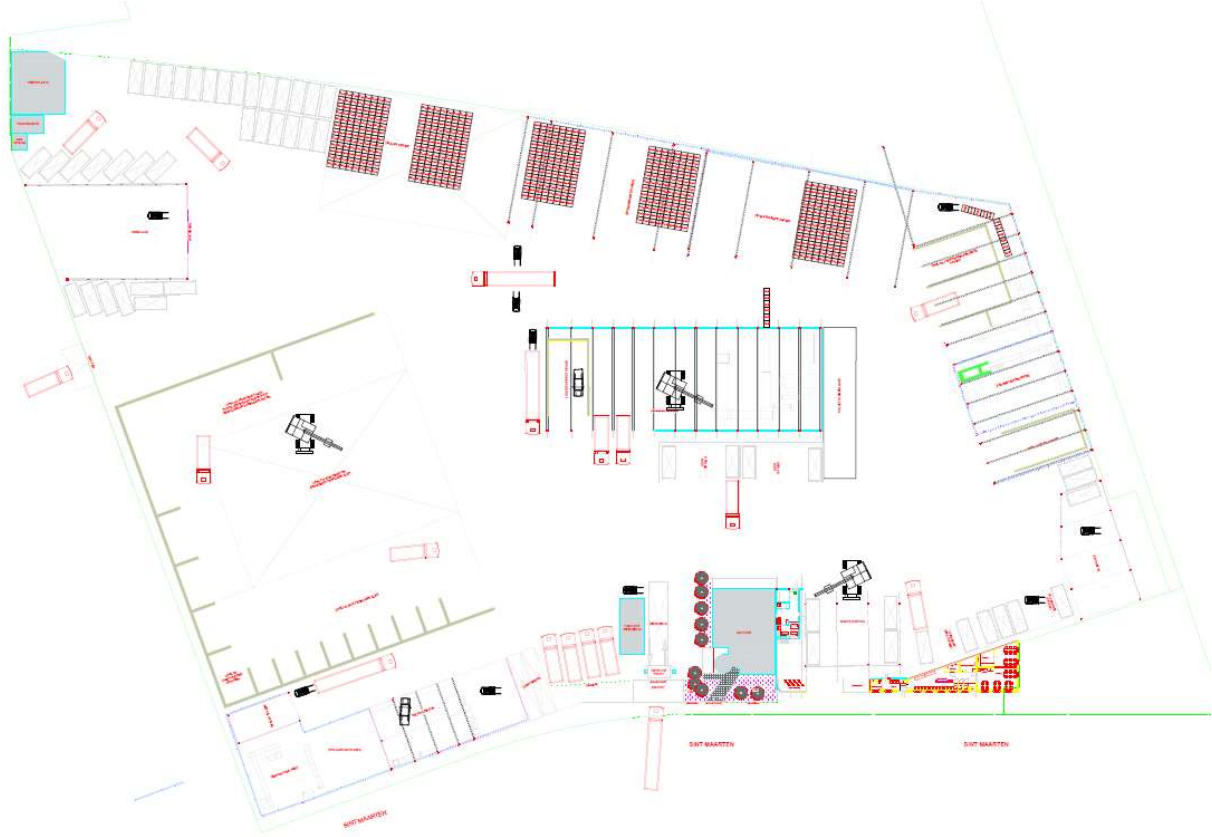


Figure 4-7 Greenfield solution impression

4.3 Improved layout plans

In this section we discuss the creation of two new layouts based on the current layout. The first layout only considers departments that can easily be moved. In the second option we also look at departments that are harder to move and thus incur higher moving cost. In Table 3-1 in Section 3.1.2 the departments are categorized based on whether they are easy to move, hard to move, fixed to another department, or not considered. In all plans, the entrance and office are considered at a fixed location. We only make use of the existing buildings.

#### 4.3.1 Creation of layout option 1

The first layout we create based on the current layout is called: “layout option 1”. For the creation of layout option 1, only the departments marked as easy to move are relocated. In this situation we also account for the fact that some departments must be located indoors and thus must be placed in an existing building. Table 4-2 lists the departments that are free to be moved and are thus considered for swapping in the CRAFT heuristic. The CRAFT heuristic is started from the current layout. Table 4-3 lists the applied swaps and the new costs. The costs shown in this table refer to the new movement cost of that solution. The CRAFT drawings can be found in Appendix F.

Table 4-2 Departments considered for the first layout

Department	Number	Main material	Cat.	Department	Number	Main material	Cat.
High quality paper Bunker	9	Paper	A	Small metal storage	26	Metal	A
Loose paper storage	10	Paper	A	WEEE- processing	27	WEEE	A
Bale storage 1	12	Paper	A	Wood A-Class	28	Wood	A
Bale storage 2	13	Paper	A	Wood B-class	29	Wood	A
Bale storage 3	14	Paper	A	Waste sorting	30	Residual waste	A
Bale storage 4	15	Paper	A	Archive individuals	31	Data	A
Bale storage 5	16	Paper	A	Plastics	32	Plastic	A
Bale storage 6	17	Paper	A	Reel splitter glass fleece	33	Glass fleece	A
Bale storage 7	18	Paper	A	Pallet storage	34	Pallets	A
Reel splitter paper	19	Paper	A	Packaging storage	35	Packaging	A
Loading bridge	20	Paper	A	Container yard	36	Empty containers	A
Loading area paper bales	21	Paper	A	Truck and trailer parking	37	-	A
Metal purchasing and sorting	25	Metal	A				

Table 4-3 Option 1 switches and new layout costs \* indexed

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	16 and 15	13,664,820	7	30 and 33	12,461,653
2	16 and 35	13,266,606	8	18 and 30	12,331,837
3	16 and 12	12,797,393	9	15 and 35	12,283,178
4	17 and 9	12,727,724	10	15 and 27	12,217,206
5	14 and 27	12,573,688	11	25 and 31	12,234,010
6	17 and 20	12,536,459			

#### 4.3.2 Creation of layout option 2

The second layout we create based on the current layout is called: “layout option 2”. This layout has a larger list of departments that can be switched by the CRAFT heuristic. For this layout we consider the departments as listed in Table 4-5. In this layout, we also consider the possibility of building new structures to house indoor departments. As with the previous layout, we start from the current layout of the company. In this evaluation, all departments but the entrance (1) and office (2) are free to be swapped. The applied swaps are listed in Table 4-4 together with the new transportation cost. The CRAFT drawings can be found in Appendix F.

Table 4-4 Option 2 switches and new layout costs \* indexed

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	16 and 15	13,664,820	5	12 and 5	12,568,569
2	16 and 35	13,266,606	6	5 and 22	12,105,652
3	16 and 7	13,034,788	7	5 and 19	11,810,426
4	16 and 8	12,875,000	8	16 and 20	12,173,248

Table 4-5 Departments considered for the second layout

Department	Num.	Main material	Cat.	Department	Num.	Main material	Cat.
Weighbridge	3	All	B	Dust extractor	22	Paper	B
Paper unloading HBC125 / sorting	4	Paper	C	Scrap yard	23	Metal	B
Paper press HBC125	5	Paper	B	Scrap shear	24	Metal	B
HBC125 shredder	6	Paper	B	Metal purchasing and sorting	25	Metal	A
Paper unloading HBC80	7	Paper	C	Small metal storage	26	Metal	A
Paper press HBC80	8	Paper	B	WEEE- processing	27	WEEE	A
High quality paper Bunker	9	Paper	A	Wood A-Class	28	Wood	A
Loose paper storage	10	Paper	A	Wood B-class	29	Wood	A
Secure data Destruction	11	Paper/ all	B	Waste sorting	30	Residual waste	A
Bale storage 1	12	Paper	A	Archive individuals	31	Data	A
Bale storage 2	13	Paper	A	Plastics	32	Plastic	A
Bale storage 3	14	Paper	A	Reel splitter glass fleecce	33	Glass fleecce	A
Bale storage 4	15	Paper	A	Pallet storage	34	Pallets	A
Bale storage 5	16	Paper	A	Packaging storage	35	Packaging	A
Bale storage 6	17	Paper	A	Container yard	36	Empty containers	A
Bale storage 7	18	Paper	A	Truck and trailer parking	37	-	A
Reel splitter paper	19	Paper	A	Transformer house	38	-	B
Loading bridge	20	Paper	A	Workshop	39	-	B
Loading area paper bales	21	Paper	A				

#### 4.3.3 Other alternative options

Next to the greenfield layout, layout option 1 and layout option 2 we want to provide some additional layouts for comparison. This is done to compare the effectiveness of the CRAFT heuristic. The first alternative is comparable to layout option 2, but now we allow all departments to be swapped. For alternative two, three and four, we make use of equal sized departments.

##### *All departments free*

In this situation we let the heuristic move all departments in the layout with no constraints on placement. The starting situation is again equal to the current situation. Leaving all departments free to be moved increases the number of possible swaps and solutions. We use the results of this option in the comparison in Section 4.4, the details of the CRAFT implementation can be found in Appendix F.

##### *Equal sized departments*

Since the CRAFT heuristic can only make swaps between adjacent or equal sized departments, we wanted to try equal departments sizes to see if it would lead to other swap choices. In this situation there are no fixed departments. We also implemented different starting solutions by altering the initial department width. Widths of 5, 7 and 14 blocks are used. We choose these numbers because they result in nice shapes of the departments. The results can be found in Section 4.4, the details of the CRAFT implementation can be found in Appendix F.

#### 4.4 Craft result comparison

In this section we discuss on the outcomes of CRAFT for the different situations, including the presented results from the greenfield layout, layout option 1 and layout option. An overall CRAFT score is determined for each of the layouts presented in Section 4.3 and the results are listed in Table 4-6. The score of a layout equals the Euclidian distance between departments, times the distance factor of 1.23, times the number of movements and this score is counted for each combination of departments. In Table 4-6, we show the scores of the layout before and after we run CRAFT as well as the total cost reduction. The columns listed as initial show the cost of the layout as we implemented in CRAFT. The columns listed as improved show the results when CRAFT is finished. We also listed the values for internal and external transportation. The cost reduction is based on the difference between the initial total score and the improved total score. From all initial results, the greenfield solution yields the lowest and thus best score. The initial greenfield score is relatively close to the score of the equal sized department options. This leads to believe it is a good solution. Craft was able to reduce the cost for all layout options. Based on the CRAFT scores, the alteration of the layouts would not yield significant savings based on driving distances (based on a cost of 1€/km). For the current layout the savings would be around 3,736 €/year, based on driving. Benefits like better throughput, time saving and increased safety are most likely more important.

Table 4-6 CRAFT scores for different situation [km/year] \* indexed

Model	Initial Total	Initial Internal	Initial External	Improved Total	Improved Internal	Improved External	CRAFT cost reduction
Current situation	14,278	7,794	6,481	10,542	5,696	4,846	3,736
Current situation with relocated weighbridge	12,658	7,797	4,858	10,569	5,834	4,735	2,086
Greenfield solution (Section 4.2)	8,808	5,037	3,771	8,705	4,934	3,771	103
Option 1 (Section 4.3.1)	14,278	7,794	6,481	12,546	6,194	6,349	1,732
Option 2 (Section 4.3.2)	14,278	7,794	6,481	12,242	5,749	6,496	2,033
Equal department size width 5	21,764	10,396	11,368	8,069	3,279	4,788	13,695
Equal department size width 7	16,927	7,466	9,464	7,797	3,545	4,249	9,133
Equal department size width 14	13,501	6,519	6,982	7,474	3,665	3,809	6,030

The results in Table 4-6 show that each of the initial layout proposals can be improved with CRAFT. For the layouts where we used equal sized departments, large improvements are found. With this we show that CRAFT is capable of delivering large improvements. The layouts with equal sized departments are not further used, since they are less capable of representing our problem.

#### 4.5 Conclusion

In this chapter we designed new layout options and performed an initial estimate of the resulting costs. The CRAFT heuristic is capable of delivering large improvements under the right conditions. For layouts that are designed with the KPIs in mind, the savings are a lot less. Based on the initial evaluation we found that the greenfield solution performs better than the current solution and that the adapted layouts also yield an improvement in expected driving distances. The total savings based on these distances are not large and larger benefits are expected on the time aspect. Time savings are a more important KPI and these results are discussed in Chapter 6.

## 5. Simulation model

In this chapter the conceptual model and its implementation are discussed. The conceptual model in Section 5.1 describes all characteristics of the system including in- and outputs. The Implemented simulation model is presented in Section 5.2. Verification and validation of the model is elaborated in Section 5.3. This chapter is closed with the conclusions in Section 5.4.

### 5.1 Conceptual model

The first step to a simulation model is the creation of a conceptual model. This section discusses the definition of a conceptual model, the goal of the simulation, assumptions and simplifications, inputs and outputs, and finally the simulation events and characteristics of the model.

#### 5.1.1 Definition of a conceptual model

There are many definitions for conceptual models to be found. Robinson (2006) defines conceptual modelling as “The abstraction of a model from a real or proposed system, which includes simplification of reality”, and “A non-software specific description of the simulation model that is to be developed, describing objectives, inputs, outputs, content, assumptions and simplifications of the model”. Pace (2000) defines conceptual modelling as “Translating modelling requirements into detailed simulation specifications (and associated simulation design) which fully satisfies requirements”. Liu, Yu, Zhang, & Nie (2011) provide an overview of conceptual modelling and its validation. A summation by Liu, Yu, Zhang, & Nie (2011), provides the mostly agreed properties of conceptual modelling:

- Conceptual modelling activity is iterative and repetitive through the whole development cycle.
- Conceptual modelling is a simplified representation of a real system.
- Conceptual modelling is independent of model code or software.
- Perspectives of both user and developer are taken into consideration

A conceptual model is an abstract model of reality, which is platform independent. A simulation model is a computerized version of a conceptual model, which is platform dependent; and a conceptual model can be implemented by multiple simulation models. A conceptual model consists of three main categories of information about the simulation and the intended application(s): the simulation context, simulation concept, and simulation elements.

#### 5.1.2 Goal

The goal of this simulation study is to gain insight into the effects of changing the layout of the company. The first step is to generate data about the current situation and verify this with the current situation. Some data is hard to determine in the real world, the simulation is used to fill these knowledge gaps. The simulation is used to generate data that is otherwise not obtainable, as discussed in Section 1.6.1. The results of the study are used to support the company in making decisions about new layout options. The current implementation of the model focusses on the movements of external vehicles that are processed on the terrain. There is large diversity in the jobs executed by the forklifts, we include the movement of bales by the forklifts and movements made by the wheel loader and terrain truck to move loose paper. Other forklift jobs can be added to the model when data is available.

#### 5.1.3 Assumptions

This section lists the assumptions made in the simulation model. Assumptions are divided into three categories: vehicles, materials and general.

##### *Vehicles*

- Driving speed is constant and limited to 2[m/s] for all vehicles
- Vehicles accelerate instantaneous to their driving speed
- The shortest route between departments is driven
- All created vehicles are processed, no vehicle leaves the system unserved
- All days of the week are equal, there is no difference in arrival rates between days
- All vehicles arrive during regular opening times and are processed the same day
- Loading weights of incoming vehicles are derived from 2019 data

- Outgoing trucks are assigned a material on creation, the loading location is depending on the occupation rate of the locations, if the material is stored at multiple locations.
- Forklifts always move two paper bales each trip
- Vehicles from class C and C1 follow the same routes on the terrain, these are modelled as one type.
- Arrivals of vehicles are independent from each other

### Materials

- All materials leave the terrain on a truck
- The bales from each baler have a fixed weight: HBC125 = 975kg, HBC80 = 675kg
- All bales from a baler are equal, there is no differentiation in paper type, only on storage location
- Bales are stored following the paper type distribution derived from the data
- Pallets and bins are not considered
- Glass fleece and paper rolls are not considered
- The following materials are considered:
  - o Paper
  - o Paper HQ (High Quality)
  - o Archive
  - o Ferro metals
  - o Non-Ferro metals
  - o Wood
  - o Plastic
  - o Waste
  - o WEEE

### General

- Movements of people are not considered
- All storage locations are treated according to the FIFO methodology
- Storage locations keep a list of stored parts
- The processing times at departments do not change with the layout
- Processing times follow the distributions derived from the data, and are independent of load size
- If there is not enough stock to fully load a vehicle, it is sent off with a reduced load size

#### 5.1.4 Simplifications

In this section we present the simplifications of the model with respect to the actual situation. Simplifications are made to reduce model complexity.

- Not all material types are considered, only the main material groups are evaluated
- Movements of cranes are not considered
- The movements of the forklifts are only linked to the movement of main materials, jobs other than moving materials are not considered.
- Not all forklift jobs are included
- Inventory, purchases and sales follow the same trend as the 2019 data, normally this would be dependent on market conditions

#### 5.1.5 Inputs

The inputs for this model are derived from the current situation. Processing times are based on the current company structure. The input to the model determines to a great extent the accuracy and validity of the model. The model input is based on weighbridge data over the year 2019, this data is discussed in Section 3.2.

- Arrival rates of vehicles per material type
- Weight of vehicle load
- Operating times of the location
- Processing times at the departments
- The layout of the terrain and the locations of the departments

### 5.1.6 Outputs

This section covers the desired outputs of the model. A distinction can be made between key-performance indicators and performance indicators. The key-performance indicators are the most important outputs of the model, these are discussed in Section 3.3. The listed outputs should all be saved in the model for further analysis of the results.

- An overview of times spent by vehicles categorised by location and process
- Utilization of forklifts
- Driving distance of forklifts to perform these jobs
- Occupation rates of road sections and locations

### 5.1.7 Simulation events

In this section, all events occurring in the simulation are discussed. To create a good working simulation model in any given software environment, the occurring events and following steps must be clear.

#### *Work day characteristics*

The working day consists of a number of time dependent events regarding opening and working hours. In this section we discuss the times at which the site is operational. Main events are: starting time of the day, break times and the end of the day event. Table 5-1 provides an overview of the official company working hours.

Table 5-1 Daily time schedule

Start of day	07:30	-
Morning pause	09:00	09:15
Pre-lunch pause	10:30	10:45
Lunch pause	12:00	12:30
Afternoon pause	15:00	15:15
End of work day	-	16:30

The start of the day happens every day of the simulation. The company starts at 7:30 and at this time vehicles are allowed on the terrain and the forklifts and other equipment is started. Figure 5-1 shows the events following the start of the day event. During break times, the staff is not working and machinery like forklifts and balers are not operated. The weighbridge is always operated, even during breaktime.



Figure 5-1 Start of day

#### *End of the day*

At the end of the day, 16:30, the entrance is closed, and the remaining vehicles on the terrain are processed. When all vehicles are processed, the systems are paused and the day is ended. The statistics of the day are stored and the simulation continues to the next day.

#### *Creation of a new vehicle*

The vehicles in the simulation are generated following a distribution derived from the company dataset over the period between 1-1-2019 and 31-12-2019. Details on the distributions can be found in Appendix D. The flowchart in Figure 5-2 is started when a vehicle must be created according to the distribution. The vehicle is created, and its parameters are set. According to the type, it is loaded or not and sent to the entrance of the terrain.

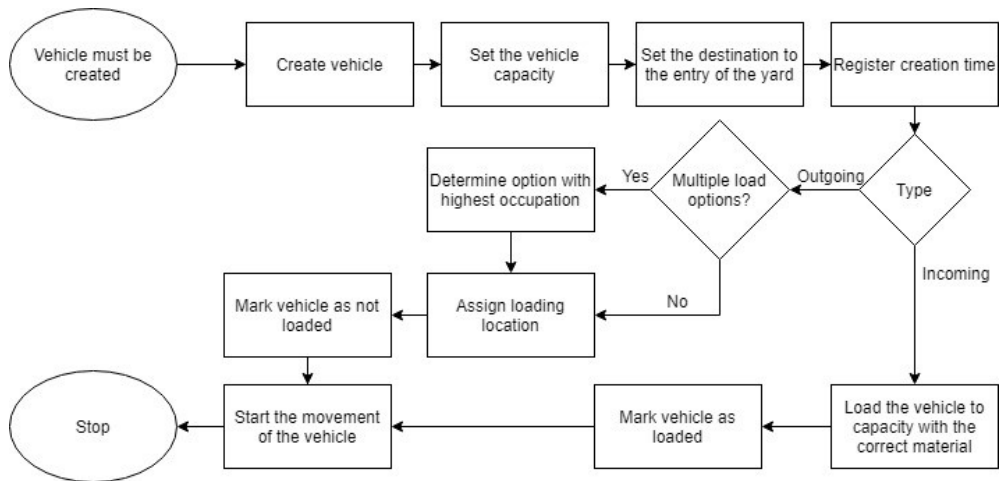


Figure 5-2 Creation of a new vehicle

### Vehicle enters the simulation

When a vehicle appears on the main road leading towards the entry of the terrain, the vehicle counter is updated and the vehicle can continue driving towards the terrain.

### Vehicle entering the terrain

When a vehicle enters the terrain, the time of entry is stored as an attribute of that vehicle. A check is done to see if a vehicle is waiting to enter the weighbridge, if so and the weighbridge area is clear, the waiting vehicle is moved, and both vehicles continue. The flowchart of this process is shown in Figure 5-3.

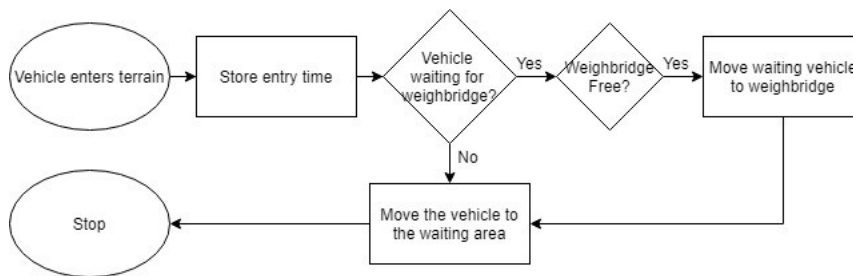


Figure 5-3 Vehicle entering the terrain

### Vehicle entering the waiting area

The section next to the office is marked as the waiting area for new vehicles. When a vehicle arrives at the waiting section, it is determined if the vehicle has to wait or can continue to the next destination. When the vehicle has entered the terrain and has reached the waiting area next to the office, its routing is determined. The flowchart of this process can be seen in Figure 5-4.

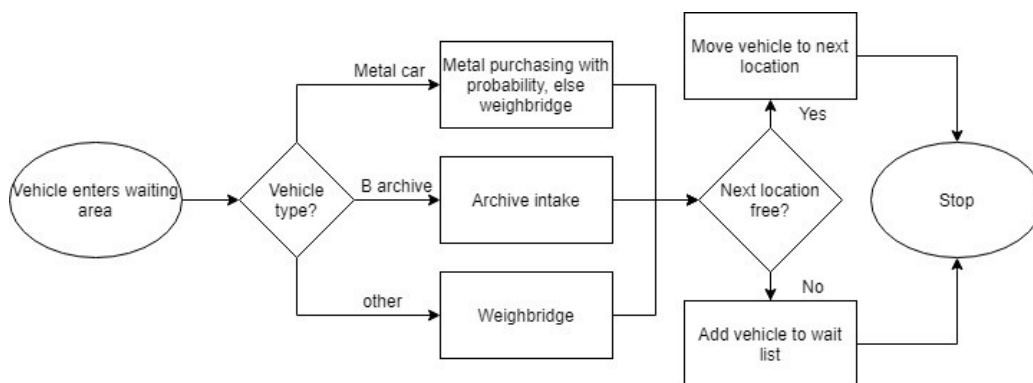


Figure 5-4 Vehicle arrives at waiting area

*Vehicle enters weighbridge*

Weighing is an important step in the processes at the company. Almost all vehicles use the weighbridge twice. When a vehicle enters the weighbridge, the logic as shown in Figure 5-5 is used. Times are stored, and a new destination for the vehicle is determined. In Section 3.2.7, we discussed the flow of vehicles on the terrain; Figure 3-8 shows a flowchart of the vehicles on the terrain, this flowchart is the base of the routing logic.

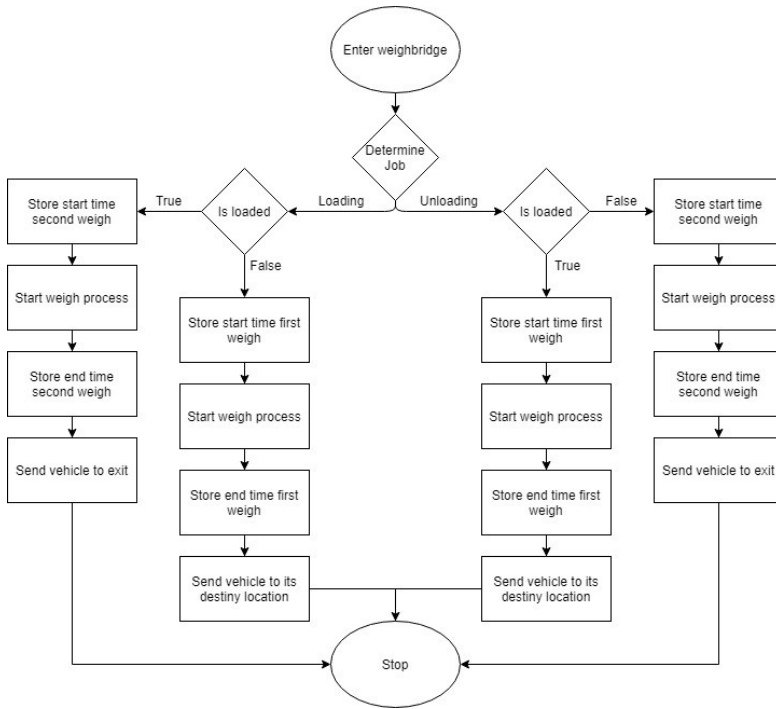


Figure 5-5 flowchart of weighbridge logic

*Vehicle arrives at a department*

Vehicles are processed on different locations, the logic is generalized for the locations. When the vehicle enters, the starting time is registered, and the needed operations are performed. When the vehicle is processed, its end time is registered and the vehicle is sent to the weighbridge. The logic flowchart can be found in Figure 5-6.

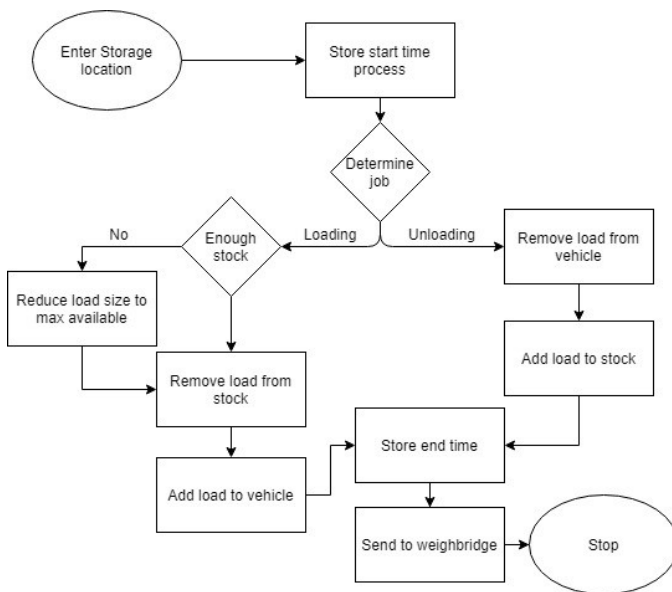


Figure 5-6 Vehicle entering material storage location

### Bale finished

When a bale is finished, a new forklift job is created if there is an even amount of bales ready. The job is then added to the job list. If a job is added, it is also checked if a forklift can start the job. This way for each set of two bales, a job is created. The process flow is presented in Figure 5-7.

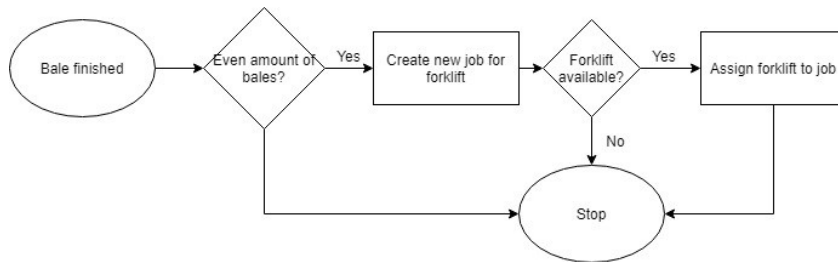


Figure 5-7 Bale finished

### Truck arrives at loading area or loading bridge

When a truck enters the loading area or the loading bridge, it is stopped for 300 seconds to prepare the truck for loading. After this time, the loading order is placed in the forklift job list. If a forklift is free, it starts loading. When the truck is loaded a 300 second timer is started to prepare the truck for transport. When the time has passed, the truck is routed to the weighbridge. The logic is presented in Figure 5-8.

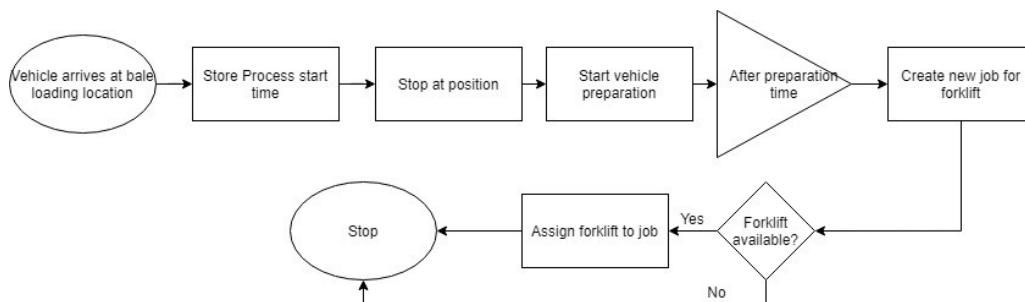


Figure 5-8 Truck requests bale loading

### Forklift finishes job

When a forklift finishes its current job, it calls for a new job. The job list is sorted and the calling forklift is searched. If the name of the forklift is found in the job-list, it is assigned the new job. If there is no current job for the forklift, it is marked as available and returns to its waiting area. When a new job is added to the job-list, this routine is activated for all forklifts in the waiting area. The logic is presented in Figure 5-9.

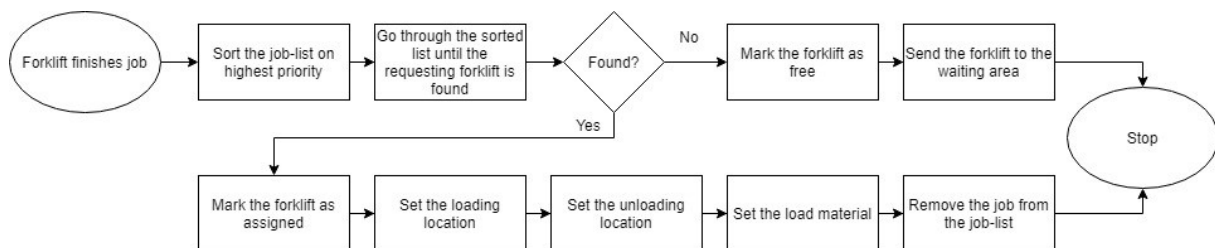


Figure 5-9 Forklift requests new job

### Forklift starts job

When a new job is found for a forklift, it is activated. Details about the loading location, load, and destination are stored with the forklift. The forklift is sent to the loading location to retrieve the load. The flowchart is presented in Figure 5-10.

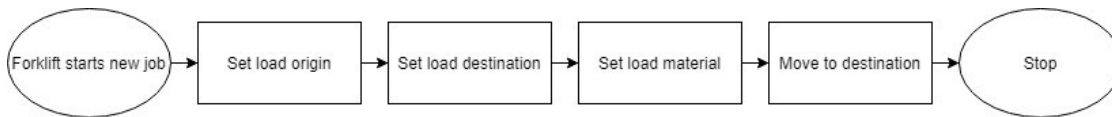


Figure 5-10 Forklift assigned to new job

### Forklift enters bale storage

When a forklift enters a bale storage, it is first determined if the forklift is loaded. From that point, the forklift is either loaded or unloaded and the material is put into stock or taken from stock. If the forklift is loaded, its load is stored in the inventory of the location. When the forklift is unloaded, it requests a new job. If that job is to load at the current location, it is directly loaded. If there is no new job, the forklift moves to the waiting area, else it moves to its loading destination. When the forklift enters a storage location empty, the desired load is searched in the inventory and loaded on the forklift. When the forklift is fully loaded, it is sent to its unloading location. The flowchart for this logic can be found in Figure 5-11.

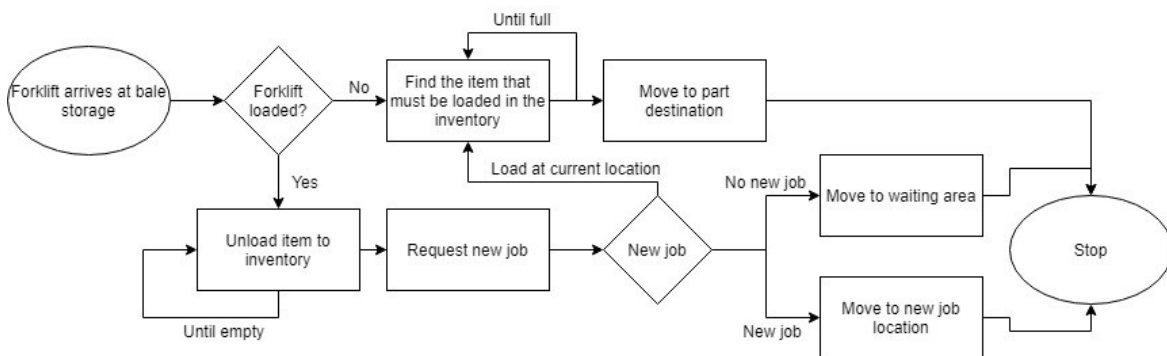


Figure 5-11 Flowchart forklift arrives at bale storage location

### 5.1.8 Simulation characteristics

Different simulation characteristics like run length, warm-up period and number of replications are elaborated on in this section.

#### Run length

The determination of the run length of the simulation is important, since it greatly influences the statistical significance of the outcomes, as well as the running time of the simulation. We set the run length to 510 days. This equals twice the amount of working days in 2019. Using multiples of this amount of working days makes it easier to compare data. The run length is more than sufficient for all possible events to happen. The run length of 2 years also enables us to see the trend in inventory.

#### Warm-up period

The warmup period in a simulation study is often an important part to increase reliability of the results. For most systems, the characteristics change when the system gets loaded. The warmup period allows to disregard the initial period of the simulation that might not be a correct representation of the system under its final load. Our simulation makes use of initial starting conditions. This means that all buffers are filled with initial inventory. Each day is started without external vehicles in the layout, and the stock levels are not regarded in this simulation. Because the system is empty at the end of each day, there is no filling of the system other than inventory. The property that each day starts with an empty system vehicle-wise, makes it that we do not need to use a warm-up period.

#### Number of replications

In order to increase statistical significance, the experiment should be repeated a number of times. The repetitions are used to show that the outcomes are not caused by chance alone. If multiple runs using different random number streams show the same results, it improves credibility. Increasing the number of runs reduces the width of the confidence intervals on the results, thus increasing statistical

significance. If the number of replications is increased too much, the duration of the simulation is increased unnecessarily. Using a statistical T-test based on a 95% confidence interval on the average waiting times of all incoming vehicles we determined the need of at least 3 replications. Law (2015) recommends to always make at least 3 to 5 replications to assess the variability of the results. Given the relatively short running time of a couple of minutes per run, we decided to make 5 runs per configuration. Details on the calculation can be found in Appendix E.

### *Experimental settings*

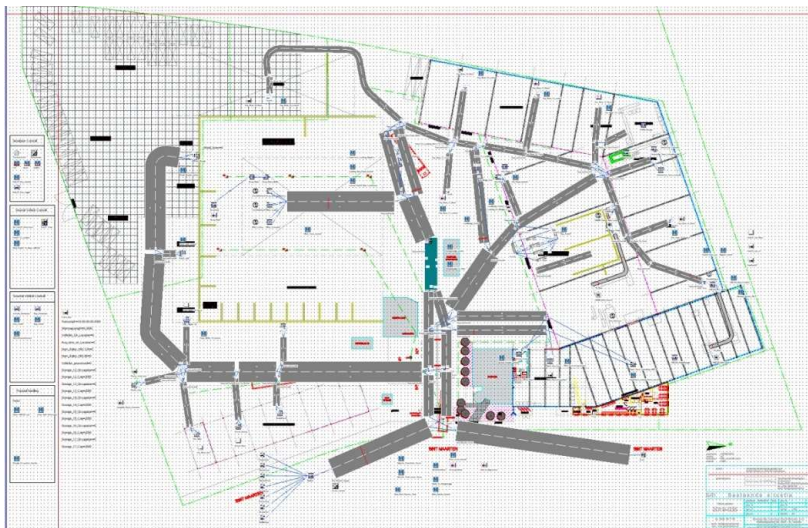
In this section we provide the settings that can be used to change the characteristics of the model. The most important experimental setting in this model is the adaptation of the layout. This can be expanded by applying the following options:

- Arrival rates for external transportation / material types
- Increasing / decreasing arrival rates for different materials
- Increasing / decreasing vehicle buffer space
- Increasing / decreasing maximal number of vehicles on the terrain

Given that it is most important to create and evaluate the current and alternative layouts, it is possible to experiment with the aforementioned factors to further analyse the layout performance.

## 5.2 Simulation model

In this section, the implemented simulation model is presented. The model is created in Technomatix Plant Simulation version 13. This program offers a large variety of tools to create a representative simulation model aligned with the conceptual model. The logic in the simulation is coded in the SimTalk 2.0 language. Mes (2019) and Bangsow (2015) provide an excellent knowledge base on the concepts and methods behind Technomatix Plant Simulation and the usage of the program. We used one base model, which is adapted to evaluate different layouts. Changes in the model are layout based; department locations, road sections and routing are adapted to match the different layouts. Figure 5-12 shows the implemented model of the current layout of Van Gerrevink. This model is used as a base and the results are compared to the results of the other models.



*Figure 5-12 PlantSimulation model current situation*

## 5.3 Verification and validation

This section elaborates on the verification and validation of the implemented model. Verification is done in Section 5.3.1. The validation process can be found in Section 5.3.2.

### 5.3.1 Verification

Verification of the model is performed to ensure that the programming and implementation of the conceptual model is correct. The model must be verified in order to improve credibility of the results.

Verification is done by discussing logic and the resulting movements in the simulation with the company. The implemented model is compared to the logic given in Section 5.1. The model is run to generate initial results and check the behaviour of the model. Visual checks are used to see if the vehicles are following the logic as we describe in the flowcharts. Important steps like sending the vehicles to the correct location, using the correct routing and time at different locations are checked. The movements of the forklifts are checked and corrected where needed. During this process we found multiple vehicles that followed weird routings, of ended at incorrect locations. All of these issues were corrected before continuing running the model.

5.3.2 Validation

Validation is performed to ensure the results of the simulation are valid and can be used. The model is validated using multiple methods. The model is compared to reality using visualization of movements. We discussed the implemented model and layout with the company to see if it is correct. The movements of the vehicles and materials through the simulation model correspond to the movements on the yard. From this we conclude that the implemented vehicle movements are valid. From the company data, we found that for the material classes we use, there are 25,822 vehicles registered over 2019. Over a period of 10 years, we find an average arrival rate of 25,083 vehicles per year in the simulation model. This is a deviation of about 3%, which we deem accurate. The arrival rate of vehicles (Appendix G) in the simulation runs is almost equal to the arrival rate determined from the company data (Chapter 3). In Table 5-2 we compare the times registered by the weighbridge to the data from the model to see if it corresponds. Between the data from the weighbridge and the simulation we find differences of varying magnitudes. Part of these differences can be explained based on the implemented rules in the model. One of the drawbacks in the model is that right of way is determined by the location of the vehicle and not between drivers. We see for instance that vehicles hauling wood take longer in the simulation, where they have to wait for vehicles coming from the paper area. Tweaking processing times can help to reduce the differences. We choose not to do this, since we are adapting the layouts and thus changing the driving properties. The loading of paper trucks is relatively fast in the simulation; this is because the forklift only moves bales, and storing and retrieving bales has no duration in the simulation.

Table 5-2 Vehicle time comparison in minutes \* indexed

Vehicle	Real data	Simulation data	Deviation %	Vehicle	Real data	Simulation data	Deviation %
Paper truck in	6:06	23:07	-12.9	Wood truck out	19:27	23:36	4.5
Paper truck out	7:46	3:51	-34.2	Ferro truck in	17:18	22:25	70.4
Paper car in	16:46	15:06	-4.1	Non-ferro car in	5:03	23:20	-19.7
Wood truck in	21:48	16:12	40.2				

5.4 Conclusions

This chapter describes the discrete event model, from conceptual model to implementation and verification and validation. Flowcharts are used to depict the logic of she simulation model. At each occurring event a part of the logic is activated. Based on the logic and parameters in the conceptual model, the simulation model is developed. The verification of this model made sure that it represented the conceptual model and behaves as expected. The model is validated based on movements, vehicle arrivals and weights. We found the movements of vehicles in the model to be comparable to the movements in the model. The amount of vehicles that is generated by the simulation model corresponds to the yearly vehicle throughput of the company. The times spent on the terrain deviate a bit more than expected. We found differences in the time comparison between the model and the data from the company. This difference is explained by the priority rules in the model. Where in real life the drivers are considerate of each other, the model uses strict rules based on the location of the vehicle instead of waiting time. This difference makes that in the model vehicles coming from certain locations get priority over others, shifting the time averages.

## 6. Determination of layout performance using simulation

This chapter discusses the results from the simulation model created in Chapter 5. The performance of the layouts is measured using the KPIs as discussed in Chapter 3. Waiting times of the different vehicles for each of the layouts can be found in Section 6.1. Utilization of locations and vehicles is analysed in Section 6.2. This is followed by a layout comparison based on driven distances in Section 6.3. In Section 6.4 we compare the average number of vehicles on the terrain for each of the layouts. Section 6.5 is about the utilization of the forklifts we modelled. We draw our conclusions about the different layouts in Section 6.6. Tables with detailed information on the simulation run results can be found in Appendix G. We can divide the layouts based on what their improvements are focussed on, internal transportation, external transportation, or a mixture of these. The current situation with the relocated and double weighbridge is specifically focussed on improving the external transportation, we expect to see improvements in the KPIs for external vehicles and not so much for internal transportation. The greenfield layout is designed to improve both internal and external transportation, and we expect to see improvements in both fields. Layout option 1 and layout option 2 are more detailed towards internal transportation, and we expect to see improvements in this field and not so much for external vehicles.

### 6.1 Waiting times

This section is focussed on the waiting times of the vehicles entering the terrain, external transportation. The section is divided into three subsections. Subsection 6.1.1 elaborates on the average waiting times for vehicles in the different scenarios. We compare the average waiting time per layout and look at the differences compared to the current layout. Subsection 6.1.2 looks at the time spent on the terrain. Reducing the total average time vehicles spent on the terrain benefits the customers as well as the company. Subsection 6.1.3 continues with the variance in waiting times. Reducing the variance of the time spent on the terrain makes it easier to predict how long a vehicle needs to be at the company. Subsection 6.1.4 looks into the maximum waiting times experienced by vehicles in the different layouts. A lower maximum waiting time is preferred, since waiting is a loss of time. The improvement method we used, CRAFT, did not take waiting times into account, it is only considering distance and the amount of trips. With the simulation, we are also able to draw conclusions on the waiting times and other time related factors.

#### 6.1.1 Average waiting times

The average experienced waiting times are compared in this section. In Table 6-1, we summarised the results from different layout options. More detailed results can be found in Appendix G. All results are compared to the current layout of the terrain. The best performing layout based on average waiting time is the greenfield layout with an improvement of 55.7% on average waiting time for external vehicles. For layout option 1 and layout option 2 there is no change in average waiting time found. When comparing the current situation to the situation with the moved and doubled weighbridge, we see an average improvement in waiting time of 319 seconds per vehicle. Assuming 25,000 vehicles per year, this would save roughly 750 hours of waiting time for external vehicles. These results are in line with our expectations. The layout with the moved weighbridge and the greenfield layout both show nice improvements, where for layout option 1 and layout option 2 no improvement is found.

Table 6-1 Average waiting time comparison \* indexed

Situation	Average waiting time [seconds]	Improvement [seconds]	Improvement [%]
Current situation	768	-	-
Current situation with relocated double weighbridge	448	319	41.6
Greenfield solution (Section 4.2)	340	428	55.7
Option 1 (Section 4.3.1)	768	0	0.0
Option 2 (Section 4.3.2)	771	-3	-0.4

### 6.1.2 Time spent on the terrain

In this subsection the time spent on the terrain is compared between multiple layout options. We use the total time spent on the terrain as a measure to see the effects of a layout change. The inputs for the different models are equal, the only change is the layout and the routing of vehicles. A reduction of time spent on the terrain means that more vehicles can be processed while maintaining the same level of service. The total time spent on the terrain is a combination of driving time, processing time and waiting time. Since processing times are equal, improvements are to be found in waiting time reduction and driving distance reduction. In Table 6-2 we summarise the results from the simulation runs about the total time spent on the terrain. Here again, we find option 1 and option 2 to be performing in a similar way as the current layout for external transportation. The layout with the relocated and doubled weighbridge reduced the average total time spent on the terrain by roughly 10%. The Greenfield solution performs even better with a reduction of roughly 20%.

Table 6-2 Total time spent on the terrain \*indexed

Situation	Average time on location [seconds]	Improvement [seconds]	Improvement [%]
Current situation (Base-Line)	2,994	-	-
Current situation with relocated double weighbridge	2,701	293	9.8
Greenfield solution (Section 4.2)	2,420	574	19.2
Option 1 (Section 4.3.1)	2,977	18	0,6
Option 2 (Section 4.3.2)	2,994	0	0

### 6.1.3 Variance in waiting times

The variance in expected waiting times are compared in this section. A lower variance indicates a lower spread in waiting times. In Table 6-3, we summarise the results from the different layout options. All results are compared to the current layout situation. The variance in waiting times gives an indication about how good the waiting time can be estimated. The best performing layout based on variation in waiting times is the greenfield solution, with an improvement of 41.2%. Option 1 and option 2 even show a small decrease in performance, for this we have not found an explanation. The layout with the relocated and doubled weighbridge shows a performance increase of 25.8%.

Table 6-3 Variance in waiting time \*indexed

Situation	Variance in waiting time	Improvement	Improvement [%]
Current situation (Base-Line)	466,444	-	-
Current situation with relocated double weighbridge	346,326	120,118	25.8
Greenfield solution (Section 4.2)	274,251	192,193	41.2
Option 1 (Section 4.3.1)	468,659	-2,215	-0.5
Option 2 (Section 4.3.2)	472,114	-5,670	-1.2

### 6.1.4 Maximum waiting times

The maximum experienced waiting times are compared in this section. In Table 6-4, we summarise the results from the different layouts. More detailed results can be found in Appendix G. All results are compared to the current layout situation. We find little difference in the maximal experienced waiting times on the terrain. We expect that the larger waiting times are caused by blockage of the scrapyard, where vehicles have to wait in line for processing. It is also possible that it is caused by the arrival of multiple trailers that must be loaded with paper bales and must wait for their turn.

Table 6-4 Maximum waiting time comparison \*indexed

Situation	Maximum waiting time [seconds]	Improvement [seconds]	Improvement [%]
Current situation (Base-Line)	20,844	-	-
Current situation with relocated double weighbridge	20,964	-120	-0.58
Greenfield solution (Section 4.2)	21,228	-384	-0.84
Option 1 (Section 4.3.1)	20,522	322	1.5
Option 2 (Section 4.3.2)	20,284	560	2.7

### 6.1.5 Conclusion

The layout of the company does have an effect on the waiting times experienced by the external vehicles. For layout option 1 and option 2 the results are comparable to the current situation, this is logical since changes in these layouts mainly effect internal transport. When we compare the current situation with the moved and doubled weighbridge layout and the greenfield layout, improvements are found. The layout with the moved and doubled weighbridge shows a performance increase of 41.6% which equals to a reduction of roughly waiting 750 hours. When the greenfield layout would be implemented, roughly 1,014 waiting hours are expected to be saved.

### 6.2 Utilization of locations and roads

This section looks into the utilization of locations and road sections. First, the occupation between locations is reviewed. Next, the usage of road sections is discussed. We defined the road sections as the parts of road in the simulation that surround departments or are used to connect departments.

In the current situation we find from the simulation that the sections around the weighbridge, paper unloading and metal unloading are the most used. The results for layout option 1 and option 2 are almost identical to the results of the current layout. We will focus on the differences between the current layout, the greenfield solution and the solution with the relocated weighbridge.

In each of the layouts, we find the paper unloading area to be the most in use. Looking at the number of vehicles arriving combined with the processing time this is logical. The weighbridge is the second most used department. For the layout with the double weighbridge and the greenfield solution (where weighbridge capacity is doubled) we find the individual weighbridges ranked below the metal unloading area.

When looking at the usage of different road sections we also identify some differences between the layouts. For the current situation we find the sections leading towards the weighbridge as the most used sections. For the greenfield layout and the relocated weighbridge layout we find that the higher utilization is around the metal yard. This is mainly caused by a reduction of the pressure on the area around the weighbridge. The occupation of the road section around the metal yard itself is almost equal in all layout options.

### 6.3 Driven distances

In this section we compare the driven distances of the vehicles entering the terrain. The driven distances are a measure of how well the departments are positioned and how good the routing is. The aim is to reduce driven distances and increase safety. When we compare the results from the simulation in Table 6-5, we see that the current layout can indeed be improved on the driven distances. The greenfield solution provides the largest reduction with an improvement of 26.2% driven distance reduction. For the layout with the relocated and doubled weighbridge an improvement of 12% is found. Layout option 1 and option 2 again show little to no improvement on driven distances for external vehicles, which is in line with the results from CRAFT. The driven distances are also compared to the CRAFT results (Section 4.4, Table 4-6). We find the distances driven in the simulation to be larger than the distances calculated using CRAFT. This result was to be expected, since CRAFT uses Euclidian distances with a correction factor where the simulation model uses the actual routing. CRAFT also does not account for the distance driven by an empty vehicle, CRAFT only looks at material movement. In

the CRAFT model of the current situation we estimated 6,481Km to be driven by external vehicles, this is roughly half of the resulting distance from the simulation which includes the return distance. Table 6-5 also shows the expected improvements from CRAFT. We see that the magnitude of the CRAFT improvements are consistent with the improvements found in the simulation.

Table 6-5 Simulation results driven distance \* indexed

Situation	Total expected driven distance per year simulation [km]	Improvement [km]	Improvement simulation [%]	Total expected driven distance per year CRAFT [km]	Improvement CRAFT external [%]
Current situation (Base-Line)	13,258	-	-	6,481	-
Current situation with relocated double weighbridge	11,661	1,597	12.0	4,735	26.9
Greenfield solution (Section 4.2)	9,783	3,475	26.2	3,771	41.8
Option 1 (Section 4.3.1)	12,980	278	2.1	6,349	2.0
Option 2 (Section 4.3.2)	13,258	0	0	6,496	-0.23

#### 6.4 Average number of vehicles present at the same time

In this section we compare the average number of external vehicles on the location at the same time. A lower number of vehicles means that there is more space for manoeuvring and the throughput is expected to be larger. Increasing the throughput means that the company can increase its volumes while maintaining their level of service and working pressure. As with the previous results, layout option 1 and option 2 show little to no improvement on the average number of vehicles on location. The improved throughput of the greenfield layout and the layout with the relocated weighbridge result in a decrease of the average number of vehicles on the location.

Table 6-6 Simulation results average number of vehicles on location \* indexed

Situation	Average number of vehicles on location	Improvement	Improvement [%]
Current situation (Base-Line)	10.31	-	-
Current situation with relocated double weighbridge	9.87	0.44	4.3
Greenfield solution (Section 4.2)	9.08	1.23	11.9
Option 1 (Section 4.3.1)	10.26	0.06	0.6
Option 2 (Section 4.3.2)	10.31	0	0

#### 6.5 Forklift utilization

In this section we focus on the utilization of the internal transportation vehicles used for the transportation of paper. The internal transportation vehicles for the other jobs are not well enough incorporated in the simulation. In the simulation model, 4 vehicles are used for the handling of paper: the large bale clamp, the small bale clamp, the wheel loader, and the truck. The total driving distance of these vehicles is stored and can be compared. The driving speed of the vehicles is set to 2 m/s, this is used to calculate the average driving time per day. For this comparison we use only the driven distance to compare the layouts. The times needed for picking up and storing items is not accounted for and seen as an equal factor for each layout. The resulting distances can be found in Table 6-7. From the results it becomes clear that there are improvements possible in the utilization of the vehicles. If driving time can be reduced by changing the layout, it means that the forklift becomes available for other jobs, or can handle more products in the same time period. For the greenfield solution, an improvement of 9.8 kilometres per day on average is found, which would be around an hour and twenty minutes of driving with the selected speed. The layout with the relocated weighbridge has

about the same driving requirements as the current situation, this is logical since the storage and production locations are not altered. For layout option 1 and option 2 we also found an improvement in driving distance. These two layouts are more based on the relocation of production and storage locations.

Table 6-7 Distance comparison internal transportation in average kilometres per day \* indexed

Situation	Current situation (Base-Line)	Current situation with relocated double weighbridge	Greenfield solution (Section 4.2)	Option 1 (Section 4.3.1)	Option 2 (Section 4.3.2)
<b>Large bale clamp</b>	74.7	74.7	49.8	61.2	68.3
Improvement	-	0.0	24.9	13.5	6.4
Improvement [%]	0.0	0.0	0.0	0.0	0.0
<b>Small bale clamp</b>	7.0	6.7	5.6	5.6	5.6
Improvement	-	0.3	1.5	1.5	1.5
Improvement [%]	0.0	0.0	0.0	0.0	0.0
<b>Wheel loader</b>	8.8	9.1	5.9	9.1	9.1
Improvement	-	-0.3	2.9	-0.3	-0.3
Improvement [%]	0.0	0.0	0.0	0.0	0.0
<b>Terrain truck</b>	1.8	1.5	2.3	1.5	1.8
Improvement	-	0.3	-0.6	0.3	0.0
Improvement [%]	-	16.7	-33.3	16.7	0

## 6.6 Conclusions

After completing the simulation studies, we can conclude that improvements to the current layout can be made. The current layout is used as the benchmark to which all other layouts are compared. In Figure 6-1 we provide an overview of the discussed KPIs and make it easier to see the differences between the layouts. The greenfield layout we created performed best on all tested KPIs. For external transportation the layout with the moved and doubles weighbridge performed second best. Layout option 1 and option 2 perform roughly the same for external vehicles, but improvements are found for internal transportations. Between the two, option 1 performed better than option 2. The layout with the relocated and doubled weighbridge showed little to no improvement for internal transportation distances. Waiting times can be reduced by almost 0.5 fte each year when the weighbridge is moved.

Given that the implementation of the greenfield solution would mean that the company has to be completely closed, demolished and rebuild, it seems best to make smaller changes that also affect the KPIs. The planned remodelling of the terrain to the situation with the relocated and doubled weighbridge can be improved by implementing parts from layout option 1 and option 2. Relocating the weighbridge affects the external vehicles, but does little to non for internal transportation. From layout option 1 and option 2 we learned that altering bale storage largely affects the needed driving distances. Placing the storage locations of bales on a location more between the loading and the production area results in less driving.



Figure 6-1 Layout Comparison \* indexed

## 7. Conclusions and recommendations

With this chapter we finalize this research. First, we present our conclusions and answer the main research question. The conclusions are followed by a discussion, limitations and recommendations.

### 7.1 Conclusions

The aim of this research is to find an answer to the main research question:

**What is the performance of the current layout and how can this be improved in terms of cost, safety and utilization?**

The current location processes around 25,000 vehicles per year. From all incoming vehicles, 60% is classified as truck, 30% as car, and 10% as light truck. All outgoing vehicles are classified as truck. Looking at the materials, roughly half of all movements on the weighbridge are for paper. All metals account for another 30% of weighbridge movements. These two materials account for the majority of movements and deserve special attention in the layouts. The flow of external vehicles on the terrain is not efficient. Almost all vehicles must cross the weighbridge at the centre of the terrain twice, leading to congestion and waiting.

We used systematic layout planning and CRAFT to design alternative layouts. Systematic layout planning is used to create a layout starting from a green field. CRAFT is used in different scenarios to find improvements of the layout. The CRAFT heuristic was capable of finding improvements for all implemented problems. These improvements are relatively small compared to the design changes we wanted to evaluate.

To further analyse the layout and compare it to other solutions we created a simulation model. The conceptual model lists all details about the model and is independent of the used software. It provides the assumptions, simplifications, inputs and outputs, logic and further details of the model. We implemented the different layouts in Technomatix PlantSimulation version 13.

From our simulation model, we found the average waiting time to be 262 seconds, in our proposed remodel this is reduced to 116 seconds. The evaluated layout where only the weighbridge is moved and has its capacity doubled showed an improvement of almost 42%. On all other KPIs we were able to find improvement compared to the current layout. The different proposed layouts show varying results on different KPIs, this is because the different options are focussed on different targets.

From the results of the simulation, we draw the conclusion that the current layout can be improved. We recommend relocating the weighbridge towards the entrance of the terrain. This would greatly benefit the possible throughput and reduce waiting times and congestion at the centre of the yard. Another option that shows great impact on the driving times of the internal transportation means is clustering the different materials instead of storing them mixed around the yard. Storing bales closer between the baler and the loading area also greatly impacts the usage of forklifts.

### 7.2 Discussion

The design of a layout has a great impact on the characteristics of a company, especially in terms of logistics. The current layout of the company was sufficient many years ago, but the company kept growing. In current times, the existing layout starts to show its weaknesses. We provided an analysis of the current layout and made proposals for alternatives. We also considered the remodel plans in our analysis as an alternative layout. The application of the CRAFT heuristic for layout improvement and Systematic Layout Planning for the construction of a new layout led to the development of three other alternatives. This made a total of five layouts for us to evaluate using our simulation model. When comparing the result for the different layout, improvements are found. The results from our study show that the expected waiting times can be reduced together with driving distances. Looking specifically at the company plans of relocating the weighbridge, we can say that this is a good step

towards a better layout. During the writing of this report the permits for construction are approved. Results from this study were used to strengthen the motivation for remodelling and show the benefits.

### 7.3 Limitations

Each research has its limitations, in this section we provide the limitations of this research. Ideally we would have all data on processing times, driving times, etc, this is unfortunately not the case. We made use of the limited time registrations from the weighbridge data and did some field research to create a standard. Furthermore, we are limited on the information about all jobs and corresponding times executed by forklifts and cranes. The information at hand was too little to incorporate these transportation means well enough in the simulation models. The model is made with data on external vehicles and a very limited set of internal transportation vehicles. The provided layouts are relatively rough. In order for a layout to be implemented, a lot of further details need to be evaluated.

### 7.4 Recommendations

In this section we provide our recommendations based on our research.

- Continue with the relocation of the weighbridge. Our results show that relocating the weighbridge has a positive impact on the KPIs of the yard. By moving the weighbridge from its central location to the entrance, waiting times can be reduced.
- Improve the understanding of all tasks and jobs performed by the internal transportation means like forklifts and cranes. More details on these jobs may improve the planning process of vehicles and tasks.
- Further investigate the possibility to store bales closer between the baler and the loading area, especially bale types that are produced in high quantities should be stored with minimal driving effort.
- Finally we recommend to study the effect of separating individual customers from the trucks. In our observations we saw customers park and manoeuvre at places where they block the main routes of incoming and outgoing trucks.

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# Appendices

## A. Company certifications

The company has many certifications to show their professionalism and trustworthiness. Van Gerrevink is certified by the following standards and institutes:

- ISO 9001
- ISO 14001
- OPK
- MRF
- CA<sup>+</sup>
- Nedvang
- WEEELabex
- VIHB
- NIWO

The most common certification is the ISO 9001 certificate, which is an internationally recognised norm in the field of quality management (TÜV Nord Group, 2020). The next one, ISO 14001, is the standard that describes which requirements the environmental management system of the company must meet (NEN, 2020). A more specified certificate for waste paper companies is the OPK certificate. The OPK certificate is practical and sector-specific, which guarantees care for the environment, safety and working conditions (FNOI, 2013). Van Gerrevink is also affiliated with the MRF, which stands for “Metal recycling federation”. All members of the MRF are certified by the MRF quality mark, which shows that companies are following the law (MRF, 2020). The CA<sup>+</sup> certificate held by Van Gerrevink is important for the destruction activities. CA<sup>+</sup> contains objective standards and procedures to ensure the confidentiality of the material to be destroyed and the safety of the procedures. CA<sup>+</sup> also guarantees an adequate, efficient and closed destruction process (FNOI CA, 2013). Management of material flows is also an important part of business, nedvang (Nederland van afval naar grondstof) offers advice, registration and compensations (Nedvang, 2019). Van Gerrevink is a certified member of nedvang and proves to be a reliable partner in the recycling of materials. For the processing of electronic waste, Van Gerrevink conforms to the WEEELabex standards. WEEELabex is an organisation that certifies companies for the treatment of electronic waste. WEEELabex normative requirements lay down measures related to the protection of the environment and human health and safety through the prevention and mitigation of the adverse impacts of treatment of waste electrical and electronic equipment (WEEELabex, 2013). For all companies in the Netherlands that deal with transporting, collecting, dealing and/or mediating of company waste flows of hazardous materials, a notation on the national VIHB-list is mandatory (NIWO, 2020). For the transportation of goods, a company needs a licence. These licences are provided by NIWO (National and international road transportation organisation). NIWO tests companies every five years on the following requirements: creditworthiness, reliability, professional competence and actual establishment (NIWO, 2020).

## B. Mathematical modelling definitions

In this section, different classification criteria for mathematical models are discussed. It provides background for the different options that can be used to model the problem of this paper.

### **Linear versus nonlinear**

A mathematical model is considered to be linear if all operators in the model display linearity, that is, they can be graphically represented on a straight line. The decision variables in a linear model are always multiplied by a constant and added together (Winston, 2004). If the operators do not display linearity, the model is seen as nonlinear. A linear model can however have nonlinear expressions in it. Linear models tend to be easier to study than nonlinear models.

### **Static versus dynamic**

Static models are used to evaluate systems while they are in equilibrium, this way average performance can be determined. In static models, as opposed to a dynamic model, the decision variables do not involve sequences of decisions over multiple periods. Static models are the way to go in solving a “one-shot” problem (Winston, 2004). Dynamic models on the other hand are time-dependent, this means the state of the system changes over time. Differential equations are a typical way to represent a dynamic model. The situation at Van Gerrevink can be seen as a dynamic situation, where inventory levels and workloads change over time. In order to determine peak loads during different situations, the use of a dynamic model is preferred.

### **Explicit versus implicit**

A model is explicit if all input parameters are known and the output can be calculated in a finite series of computations. When the output parameters are known and the input must be solved for by an iterative procedure, the model is implicit.

### **Discrete versus continuous**

Discrete models treat objects as discrete, like the name implies. Discrete means that the objects can be individually separated and districted, like the number of people in a room. Continuous models represent objects in a continuous way, this means there are no individual points. A good example of this are temperatures and stresses in a solid material, the measurement results of two very close point will most likely be the same, while there is a difference over the whole. This means we can see the processes at Van Gerrevink as discrete processes.

### **Deterministic versus probabilistic or stochastic**

A deterministic model is a model with a fixed output given the input. Every set of variable states is uniquely determined by parameters in the model and the previous state. For the same input, a deterministic model always delivers the same output. Stochastic models on the other hand have a form of randomness in them, usually created from probability distributions. A stochastic model will generally yield other results each time the model is used, even with the same inputs.

### **Deductive, inductive or floating**

A deductive model is a logical structure based on a theory, so the base of the model is deducted from something. An inductive model is based on empirical findings and generalizations, these models can be derived from observations. Floating models are not based on theory or observations, but are generated based on an expected structure.

## C. Data tables

In this section tables are placed that can be used for further details but are not necessary for the continuation of the main text. The number of movements between departments as used in the CRAFT model can be found in Table C-1. The split between internal and external vehicles can be found in Table C-2 and Table C-3.

*Table C-1 Movements between departments (departments with no registered connection are excluded) \* removed for publication*

From /to	1	3	4	5	8	9	10	11	12	13	14	15	16	17	19	20	23	24	25	26	27	28	30	31	32	33	34	35	
1																													
3																													
4																													
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35																													

*Table C-2 Internal movements \* removed for publication*

	4	5	8	10	11	12	13	14	15	16	17	20	23	24	26	27	28	30	32	33	34	
4																						
5																						
8																						
9																						
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33																																		

Table C-3 External movements \* removed for publication

.	1	3	4	9	10	11	19	20	23	25	26	28	30	31	32	34	35
1																	
2																	
3																	
4																	
9																	
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25																	
26																	
28																	
30																	
31																	
32																	
34																	
35																	

## D. Overview of distributions and determination of simulation parameters

In this appendix we introduce an overview of distributions that can be used in PlantSimulation to generate process and arrival times. The following distributions are discussed;

- Constant
- Uniform
- Normal
- Lognormal
- Negative exponential
- Geometric
- Hypergeometric
- Erlang
- Weibull
- Triangle
- Binomial
- Poisson
- Gamma
- Beta
- D Empirical
- C empirical
- Empirical
- Formula

### D.1 Arrival distributions

Here the arrival distributions used in Plant Simulation are listed.

Table D-1 Average number of events per day, 255 days, arrival distribution \* indexed

Material	Class	In / Out	Location of weight registration	Total arrivals per year	Average arrivals per day	Arrival distribution	Parameter
Paper	Truck	In	Weighbridge	26,862	105	Negative exponential	*Removed
Paper	Truck	Out	Weighbridge	4,542	18	Negative exponential	
Paper high quality	Truck	In	Weighbridge	2,145	8	Negative exponential	
Paper archive	Truck	In	Weighbridge	536	2	Negative exponential	
Paper	Car	In	Weighbridge	3,730	15	Negative exponential	
Paper archive	Car	In	Archive intake	1,884	7	Negative exponential	
Metal Ferro	Truck	In	Weighbridge	6,578	26	Negative exponential	
Metal Ferro	Truck	Out	Weighbridge	885	3	Negative exponential	
Metal Ferro	Car	In	Weighbridge	4,934	19	Negative exponential	
Metal Ferro	Car	In	Metal purchasing	62	0	Negative exponential	
Metal Non-Ferro	Truck	In	Weighbridge	1,447	6	Negative exponential	
Metal Non-Ferro	Truck	Out	Weighbridge	355	1	Negative exponential	
Metal Non-Ferro	Car	In	Weighbridge	1,026	4	Negative exponential	
Metal Non-Ferro	Car	In	Metal purchasing	6,762	27	Negative exponential	
Wood	Truck	In	Weighbridge	3,689	14	Negative exponential	
Wood	Truck	Out	Weighbridge	592	2	Negative exponential	
Wood	Car	In	Weighbridge	267	1	Negative exponential	
Plastic	Truck	In	Weighbridge	1,855	7	Negative exponential	
Plastic	Truck	Out	Weighbridge	302	1	Negative exponential	
Plastic	Car	In	Weighbridge	522	2	Negative exponential	
Waste	Truck	In	Weighbridge	4,618	18	Negative exponential	
Waste	Truck	Out	Weighbridge	1,160	5	Negative exponential	
Waste	Car	In	Weighbridge	413	2	Negative exponential	
WEEE	Truck	In	Weighbridge	331	1	Negative exponential	
WEEE	Truck	Out	Weighbridge	32	0	Negative exponential	
WEEE	Car	In	Weighbridge	132	1	Negative exponential	

## D.2 Determination of the weight distributions:

To determine the weight distribution of the incoming and outgoing vehicles, the dataset over 2019 is used. For each of the vehicle types used in the simulation, a distribution is determined. For the purpose of comparing different continuous distributions, the “reliability” Python library (Reid M. , 2020) is used. To determine the best fitting distribution, we make use of the following python code;

```
//      from reliability.Fitters import Fit_Everything
//      import pandas as pd
//      df = pd.read_excel (r'C:\Users\gerri\Desktop\Papiergewicht.xlsx')
//      r = df["Gewichten"].values.tolist()
//      results = Fit_Everything(failures=r)
//      print ('The best fitting distribution was', results.best_distribution_name, 'which had parameters',
//            results.best_distribution.parameters)
```

The code fits the following distributions to the data:

- Weibull
- Weibull 3p
- Gamma 2p
- Gamma 3p
- Exponential 1p
- Exponential 2p
- LogNormal 2p
- LogNormal 3p
- Normal

For each of the distributions, the best fitting parameters per distribution are presented along with the results of two goodness-of-fit tests. Two tests are applied, the Bayesian information criterion (BIC) and the Akaike information criterion (AIC). The Bayesian information criterion is used to compare different models, the model with the lowest value of the estimator is preferred. To reduce the risk of overfitting the model by adding parameters, a penalty is incurred for each added parameter. The Akaike information criterion estimates the relative amount of information lost by a given model, and deals with the trade-off between goodness-of-fit and simplicity of the model.

Table D-2 provides an overview of all used distributions. Details on the determination of specific vehicles can be found in their corresponding section. With each vehicle type we provide the used filters in the dataset and resulting distribution outputs.

\* Most details in this appendix are removed for publication.

Table D-2 Vehicle loading weight

Material	Class	In /Out	Average Weight [kg]	Distribution	Parameters	Plant Simulation input
Paper	Truck	In	11,289	Gamma		
Paper	Truck	Out	79,939	Normal		
Paper high quality	Truck	In	25,386	Lognormal		
Paper archive	Truck	In	7,272	Lognormal		
Paper	Car	In	1,245	Normal		
Paper archive	Car	In	331	Lognormal		
Metal Ferro	Truck	In	8,857	Lognormal		
Metal Ferro	Truck	Out	76,297	Weibull		
Metal Ferro	Car	In	791	Lognormal		
Metal Ferro	Car	In	138	Lognormal		
Metal Non-Ferro	Truck	In	5,227	Lognormal		
Metal Non-Ferro	Truck	Out	29,060	Gamma		
Metal Non-Ferro	Car	In	741	Lognormal		
Metal Non-Ferro	Car	In	296	Lognormal		
Wood	Truck	In	6,944	Weibull		
Wood	Truck	Out	44,243	Weibull		
Wood	Car	In	914	Lognormal		
Plastic	Truck	In	3,349	Weibull		
Plastic	Truck	Out	25,969	Normal		
Plastic	Car	In	281	Lognormal		
Waste	Truck	In	12,376	Gamma		
Waste	Truck	Out	52,910	Lognormal		
Waste	Car	In	656	Lognormal		
WEEE	Truck	In	4,038	Exponential		
WEEE	Truck	Out	24,521	Exponential		
WEEE	Car	In	1,486	Weibull		

Paper truck in

Year	Material	Main group	In / out	Location	Class
2019		Paper; Services	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_2P							168857.485014	168871.730435
Gamma_3P							168859.536533	168880.904009
Weibull_2P							168999.667560	169013.912981
Weibull_3P							169001.632844	169023.000321
Exponential_1P							169710.682472	169717.805401
Exponential_2P							169707.928609	169722.174030
Lognormal_2P							170198.557596	170212.803017
Lognormal_3P							170200.558906	170212.803017
Normal_2P							175215.618446	175229.863867

Paper truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Paper; Services	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Normal_2P							30595.888998	30606.573262
Weibull_2P							30638.756497	30649.440761
Weibull_3P							30687.107093	30703.129600
Gamma_2P							31825.958447	31836.642710
Gamma_3P							31827.966214	31843.988720
Lognormal_2P							33044.101223	33054.785486
Lognormal_3P							33066.086898	33054.785486
Exponential_1P							34765.475649	34770.819076
Exponential_2P							34765.207636	34775.891899

#### Paper truck high quality in

Year	Materials	Main group	In / Out	Location	Class
2019		Paper	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							14542.970824	14552.145924
Lognormal_3P							14545.237617	14552.145924
Gamma_2P							14576.837680	14586.012780
Gamma_3P							14573.015759	14586.770134
Weibull_3P							14599.739608	14613.493982
Weibull_2P							14615.414770	14624.589870
Exponential_2P							14693.963308	14703.138408
Exponential_1P							14740.044864	14744.635165
Normal_2P							14984.448681	14993.623781

#### Paper truck archive

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							3218.573441	3224.925747
Lognormal_3P							3220.703684	3224.925747
Exponential_2P							3219.011698	3225.364004
Weibull_3P							3220.285223	3229.779603
Gamma_3P							3220.440873	3229.935253
Exponential_1P							3228.958867	3232.146254
Gamma_2P							3228.423734	3234.776040
Weibull_2P							3230.271279	3236.623584
Normal_2P							3399.528411	3405.880716

#### Paper car in weighbridge

Year	Materials	Main group	In / Out	Location	Class
2019		Paper	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Normal_2P							20012.927402	20023.200368
Weibull_2P							20076.782245	20087.055211
Weibull_3P							20099.997967	20115.402639
Gamma_2P							20317.093708	20115.402639
Gamma_3P							20319.103247	20334.507920
Lognormal_2P							20859.993315	20870.266282
Lognormal_3P							20893.428896	20870.266282
Exponential_1P							22015.117823	22020.255896
Exponential_2P							22011.482772	22021.755738

Paper car in archive intake

Year	Materials	Main group	In / Out	Location	Class
2019		Paper	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							7204.314223	7213.227762
Lognormal_3P							7206.333031	7213.227762
Weibull_3P							7238.836163	7252.197039
Gamma_3P							7271.422316	7284.783192
Weibull_2P							7288.002374	7296.915913
Gamma_2P							7327.257172	7336.170712
Exponential_2P							7356.518918	7365.432458
Exponential_1P							7365.939389	7370.399294
Normal_2P							8606.840708	8615.754247

Metal ferro truck in

Year	Materials	Main group	In / Out	Location	Class
2019		Ferro	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							39535.509016	39546.934798
Lognormal_3P							39524.061596	39546.934798
Weibull_3P							39906.506398	39923.642387
Weibull_2P							39996.366305	40007.792087
Gamma_3P							40078.303500	40095.439490
Gamma_2P							40168.672749	40180.098531
Exponential_2P							40414.355002	40425.780784
Exponential_1P							40442.105856	40447.819640
Normal_2P							44408.412561	44419.838343

Metal ferro truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Ferro	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_2P							6201.825551	6209.213017
Normal_2P							6213.265114	6220.652580
Weibull_3P							6227.765330	6238.826261
Gamma_2P							6372.955458	6380.342924
Gamma_3P							6376.220815	6387.281746
Lognormal_2P							6525.746337	6533.133802
Lognormal_3P							6529.233523	6533.133802
Exponential_1P							6767.468579	6771.169023
Exponential_2P							6766.452428	6773.839894

Metal ferro car in weighbridge

Year	Materials	Main group	In / Out	Location	Class
2019		Ferro	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							21961.729154	21972.578678
Lognormal_3P							21966.003932	21972.578678
Gamma_3P							21990.934612	22007.205317
Gamma_2P							22029.457884	22040.307407
Weibull_3P							22029.888741	22046.159446
Weibull_2P							22094.992430	22105.841954
Exponential_2P							22116.295037	22127.144561
Exponential_1P							22240.240993	22245.666946
Normal_2P							23253.536315	23264.385838

### Metal ferro car in metal purchasing

Year	Materials	Main group	In / Out	Location	Class
2019		Ferro	In	Metal purchasing	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_3P							200.951183	202.672986
Weibull_3P							201.833688	203.555490
Lognormal_2P							203.120189	204.542567
Lognormal_3P							205.742004	204.542567
Exponential_1P							205.874151	206.708147
Exponential_2P							205.558108	206.980486
Weibull_2P							207.911510	209.333888
Gamma_2P							208.326864	209.749242
Normal_2P							243.493252	244.915630

### Metal non-ferro truck in

Year	Materials	Main group	In / Out	Location	Class
2019		Non-Ferro	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							8294.637902	8303.018533
Lognormal_3P							8296.013639	8303.018533
Weibull_3P							8327.260623	8339.819250
Gamma_3P							8341.925225	8354.483852
Weibull_2P							8363.717692	8372.098323
Exponential_2P							8372.201808	8380.582439
Gamma_2P							8378.649670	8387.030301
Exponential_1P							8386.937901	8391.132306
Normal_2P							9106.494794	9114.875425

### Metal non-ferro truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Non-Ferro	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_2P							2440.322904	2445.812790
Weibull_2P							2440.372712	2445.862598

Weibull_3P							2441.953995	2450.136238
Gamma_3P							2444.597270	2452.779514
Lognormal_2P							2452.773893	2458.263779
Lognormal_3P							2454.971859	2458.263779
Exponential_2P							2459.739004	2465.228890
Exponential_1P							2470.960341	2473.722518
Normal_2P							2473.884480	2479.374366

#### Metal non-ferro car in weighbridge

Year	Materials	Main group	In / Out	Location	Class
2019		Non-Ferro	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_3P							4411.063093	4422.496519
Lognormal_2P							4417.133495	4424.767718
Lognormal_3P							4419.169102	4424.767718
Weibull_2P							4421.578164	4429.212388
Gamma_3P							4418.042666	4429.476092
Exponential_1P							4429.590906	4433.413952
Exponential_2P							4425.849875	4433.484098
Gamma_2P							4428.499473	4436.133697
Normal_2P							4970.104815	4977.739039

#### Metal non-ferro car in metal purchasing

Year	Materials	Main group	In / Out	Location	Class
2019		Non-Ferro	In	Metal purchasing	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							25162.946172	25174.423148
Lognormal_3P							25164.951398	25174.423148
Weibull_3P							25483.945355	25501.158204
Weibull_2P							25606.391563	25617.868539
Gamma_3P							25635.751833	25652.964682
Gamma_2P							25757.335381	25768.812357
Exponential_2P							25817.666523	25829.143499
Exponential_1P							25861.224619	25866.963979
Normal_2P							30528.511836	30539.988812

#### Wood truck in

Year	Materials	Main group	In / Out	Location	Class
2019		Wood	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_2P							22036.817004	22047.083595
Gamma_2P							22037.950624	22048.217216
Weibull_3P							22039.433097	22054.828192
Gamma_3P							22040.108911	22055.504007
Exponential_1P							22086.733439	22091.868330
Exponential_2P							22087.678306	22097.944898
Lognormal_2P							22228.189068	22238.455660
Lognormal_3P							22230.198637	22238.455660
Normal_2P							22718.895693	22729.162285

### Wood truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Wood	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_2P							3809.730097	3816.286331
Normal_2P							815.444378	3822.000612
Weibull_3P							3827.198801	3837.002392
Gamma_2P							3835.103728	3841.659962
Gamma_3P							3837.164639	3846.968230
Lognormal_2P							3851.354810	3857.911044
Lognormal_3P							3853.451691	3857.911044
Exponential_2P							4121.715902	4128.272136
Exponential_1P							4293.500405	4296.788673

### Wood car in

Year	Materials	Main group	In / Out	Location	Class
2019		Wood	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							1199.028840	1203.914196
Lognormal_3P							1201.578618	1203.914196
Gamma_2P							1203.700314	1208.585669
Gamma_3P							1204.447056	1211.703773
Weibull_3P							1208.536382	1215.793098
Weibull_2P							1211.735927	1216.621283
Exponential_2P							1216.462165	1221.347521
Exponential_1P							1229.546957	1232.012872
Normal_2P							1263.649542	1268.534898

### Plastic truck in

Year	Materials	Main group	In / Out	Location	Class
2019		Plastics	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_3P							10136.552933	10149.866188
Weibull_3P							10145.257491	10158.570747
Exponential_2P							10173.617237	10182.499131
Weibull_2P							10177.724210	10186.606103
Exponential_1P							10182.725685	10187.169817
Gamma_2P							10180.064997	10188.946891
Lognormal_2P							10256.353437	10265.235330
Lognormal_3P							10263.362831	10265.235330
Normal_2P							10904.442663	10913.324556

#### Plastic truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Plastics	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Normal_2P							1960.590150	1965.739608
Weibull_2P							1962.519349	1967.668807
Weibull_3P							1975.474755	1983.136518
Gamma_2P							1982.094165	1987.243623
Gamma_3P							1984.216590	1991.878352
Lognormal_2P							2005.242189	2010.391647
Lognormal_3P							2007.495163	2010.391647
Exponential_2P							2060.786396	2065.935854
Exponential_1P							2080.505790	2083.100916

#### Plastic car in

Year	Materials	Main group	In / Out	Location	Class
2019		Plastic	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							1883.236045	1889.531041
Lognormal_3P							1885.272554	1889.531041
Gamma_3P							1930.883532	1940.290952
Gamma_2P							1942.371006	1948.666002
Exponential_2P							1944.538990	1950.833986
Weibull_3P							1944.300273	1953.707693
Weibull_2P							1972.210501	1978.505497
Exponential_1P							1981.783002	1984.942058
Normal_2P							2234.665172	2240.960168

#### Waste truck in

Year	Materials	Main group	In / Out	Location	Class
2019		Waste	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_2P							29409.781321	29420.497708

Weibull_2P							29410.751855	29421.468243
Gamma_3P							29406.573190	29422.643945
Weibull_3P							29408.972979	29425.043733
Exponential_1P							29451.924922	29457.284390
Exponential_2P							29453.185412	29463.901799
Lognormal_2P							29652.508881	29663.225269
Lognormal_3P							29654.516525	29663.225269
Normal_2P							31083.943128	31094.659515

### Waste truck out

Year	Materials	Main group	In / Out	Location	Class
2019		Waste	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							2001.520501	2006.710775
Lognormal_3P							1998.641632	2006.710775
Gamma_3P							2018.814691	2026.538948
Gamma_2P							2028.887514	2034.077787
Weibull_3P							2032.008542	2039.732799
Exponential_2P							2044.601655	2049.791928
Weibull_2P							2056.596932	2061.787205
Exponential_1P							2098.912211	2101.527336
Normal_2P							2111.093896	2116.284169

### Waste car in

Year	Materials	Main group	In / Out	Location	Class
2019		Waste	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Lognormal_2P							1792.153194	1797.963757
Lognormal_3P							1795.815849	1797.963757
Exponential_2P							1799.853699	1805.664262
Gamma_2P							1801.973422	1807.783985
Gamma_3P							1801.749518	1810.420615
Weibull_3P							1801.910648	1810.581746
Weibull_2P							1807.718792	1813.529355
Exponential_1P							1810.648170	1813.568153
Normal_2P							1946.086200	1951.896763

### WEEE truck in

Year	Materials	Main group	In / Out	Location	Class
2019		WEEE	In	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_3P							1854.804296	1862.766276
Gamma_3P							1855.247908	1863.209888
Exponential_1P							1861.660534	1864.351886

Exponential_2P							1860.928424	1866.274109
Weibull_2P							1860.947039	1866.292724
Gamma_2P							1862.681204	1868.026889
Lognormal_2P							1863.275869	1868.621554
Lognormal_3P							1865.859641	1868.621554
Normal_2P							2029.594715	2034.940399

#### WEEE truck out

Year	Materials	Main group	In / Out	Location	Class
2019		WEEE	Out	Weighbridge	C; C1

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Weibull_3P							178.884111	176.649226
Gamma_3P							183.973887	181.739001
Exponential_1P							223.155056	223.108507
Gamma_2P							224.404017	223.699807
Weibull_2P							224.404017	223.879428
Lognormal_2P							224.944103	224.239894
Lognormal_3P							189.541767	224.239894
Exponential_2P							224.966902	224.262692
Normal_2P							235.747904	235.043694

#### WEEE car in

Year	Materials	Main group	In / Out	Location	Class
2019		WEEE	In	Weighbridge	B

	Alpha	Beta	Gamma	Mu	Sigma	Lambda	AICc	BIC
Distribution								
Gamma_3P							683.509416	688.651544
Weibull_3P							683.728201	688.870328
Weibull_2P							689.022326	692.545097
Lognormal_2P							689.022326	693.516485
Lognormal_3P							692.266177	693.516485
Gamma_2P							691.138131	694.660902
Exponential_1P							702.673453	704.480167
Exponential_2P							704.639883	708.162654
Normal_2P							780.862530	784.385301

## E. Number of replications

Here we discuss the determination of the number of replications for the simulation using a run length of 510 days. The number of replications are tested on two different KPIS, average waiting time and average turnaround time. We used a T-test to determine the needed number of replications for a 95% confidence interval. In Table E-1 and Table E-2 we determined the number of replications needed for the average waiting time and for the average turnaround time. From these calculations we find that from three replications the result is sufficient for a 95% confidence level.

*Table E-1 Number of replications based on average waiting time*

n	KPI (AVG waiting time all vehicles)	Mean	Variance	Tvalue	Error	Max error	Result
1	788			0,05			
2	765	776	94	12,706	0,195	0,048	0,147
3	759	771	82	4,303	0,051	0,048	0,003
4	762	768	62	3,182	0,028	0,048	-0,020
5	776	771	50	2,776	0,019	0,048	-0,028
6	765	771	41	2,571	0,015	0,048	-0,032
7	762	768	38	2,447	0,013	0,048	-0,035

*Table E-2 Number of replications based on average turnaround time*

n	KPI (AVG turnaround time)	Mean	Variance	Tvalue	Error	Max error	Result
1	3,024			0,05			
2	2,992	3,009	177	12,706	0,068	0,048	0,021
3	2,983	3,000	159	4,303	0,018	0,048	-0,030
4	2,986	2,997	122	3,182	0,010	0,048	-0,038
5	3,006	2,997	99	2,776	0,007	0,048	-0,041
6	2,997	2,997	79	2,571	0,005	0,048	-0,042
7	2,989	2,997	70	2,447	0,004	0,048	-0,043

## F. CRAFT results

In this appendix we provide the different layouts as they are implemented in the CRAFT heuristic. We provide the CRAFT input and output frames, as well as the applied swaps. The following layouts are provided:

- Current layout
- Current layout with weighbridge moved
- Greenfield layout
- Layout option 1
- Layout option 2
- Equal department size width 5
- Equal department size width 7
- Equal department size width 14

The black lines in the figures represent a flow between the centroids of the departments.

## F.1 Current layout CRAFT

Figure F-1 provides the CRAFT input for the current layout. Figure F-2 provides the output from CRAFT. The swaps used to made the transition from input to output are provided in Table F-1. The other sections with CRAFT results follow this same setup.

\* All values in this appendix are indexed.

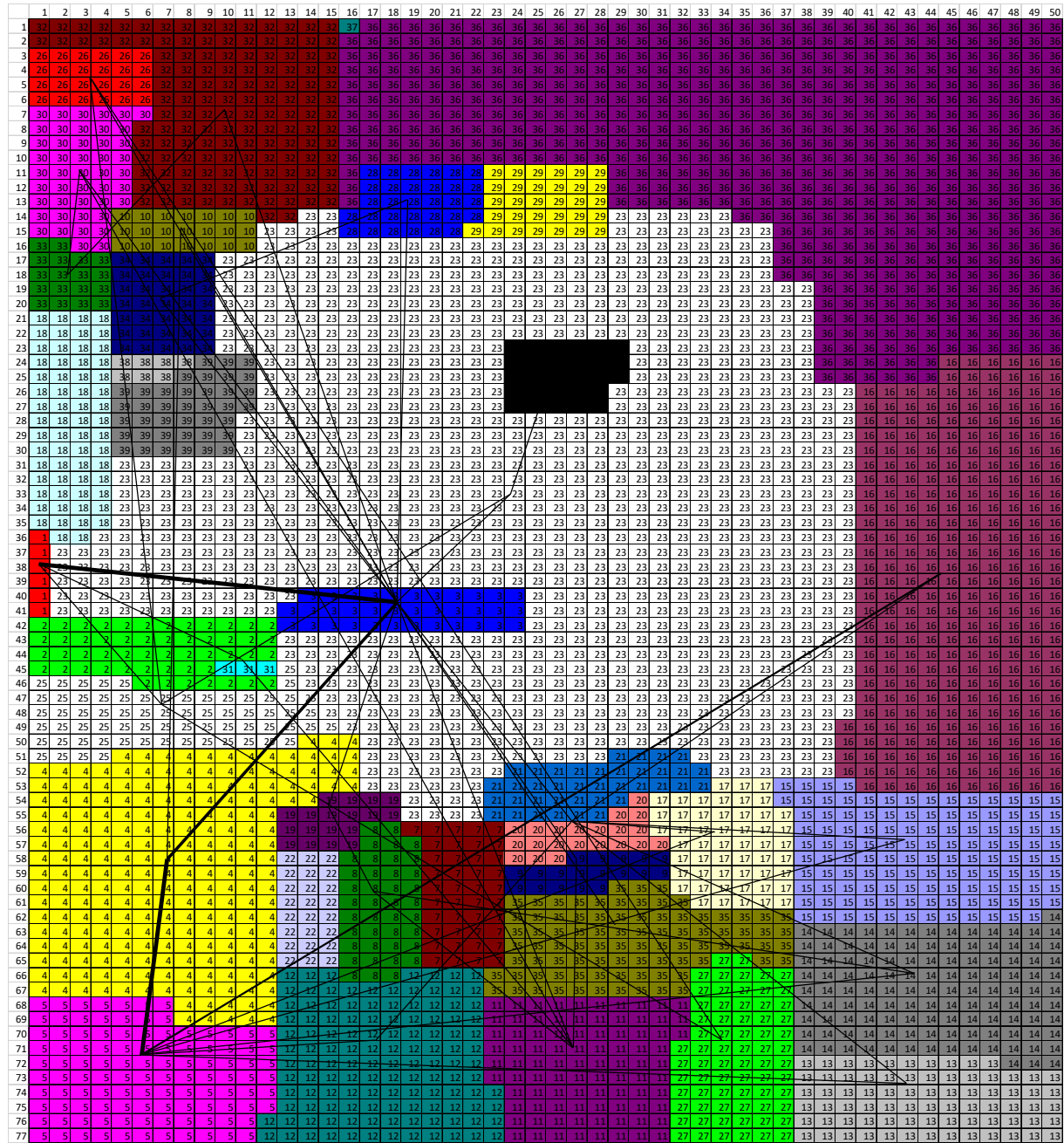


Figure F-1 Current layout CRAFT input

Table F-1 Current layout switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	2 and 3	12,335,423	6	12 and 5	10,984,157
2	16 and 15	12,071,878	7	5 and 22	10,521,240
3	16 and 35	11,682,197	8	5 and 19	10,226,523
4	16 and 7	11,450,376	9	23 and 2	10,195,477
5	16 and 8	11,290,588	10	23 and 31	10,496,584

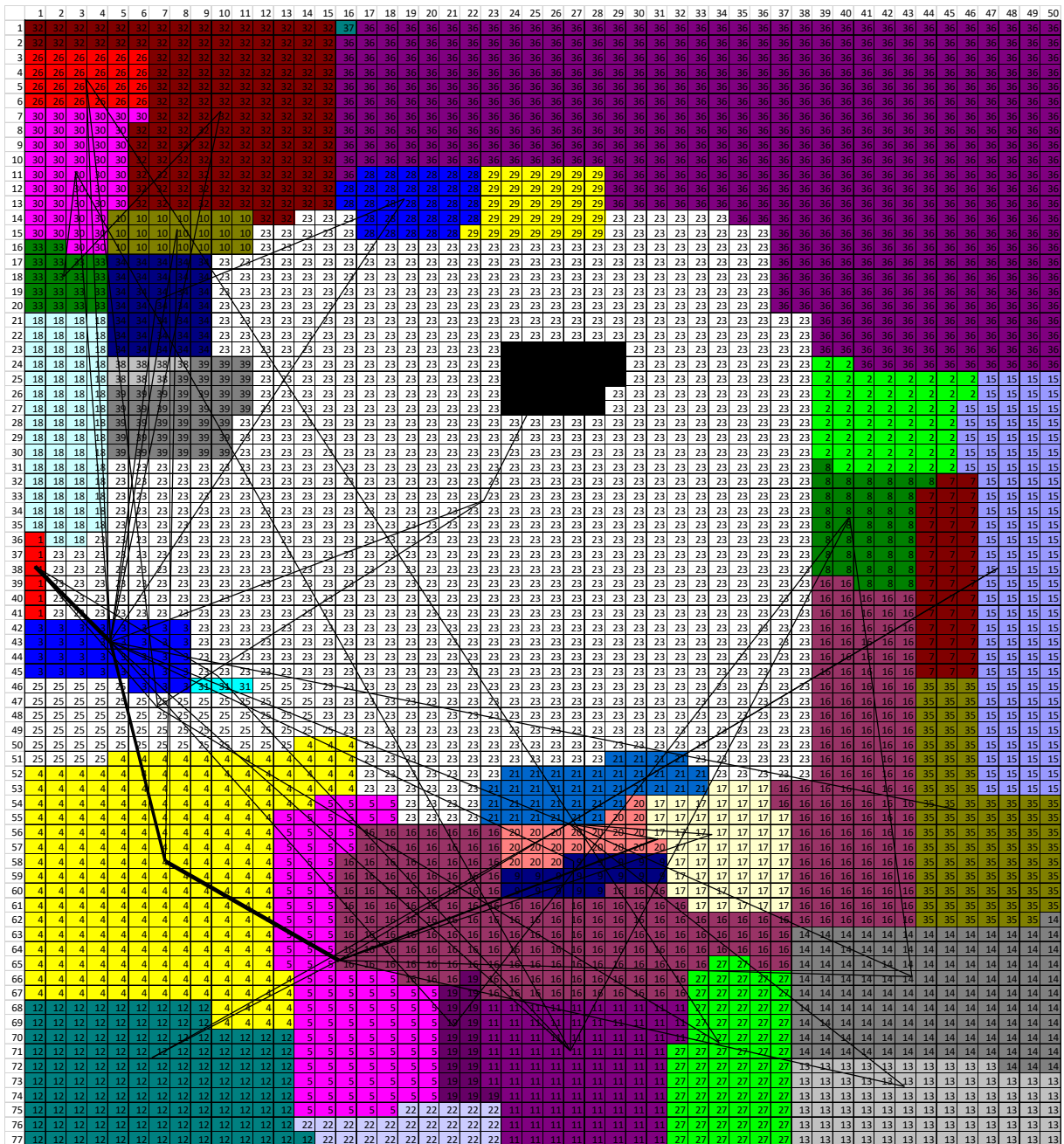


Figure F-2 Current layout CRAFT output

## F.2 Current layout with weighbridge moved CRAFT

Figure F-3 provides the CRAFT input for the current layout. Figure F-4 provides the output from CRAFT. The swaps used to made the transition from input to output are provided in Table F-2.

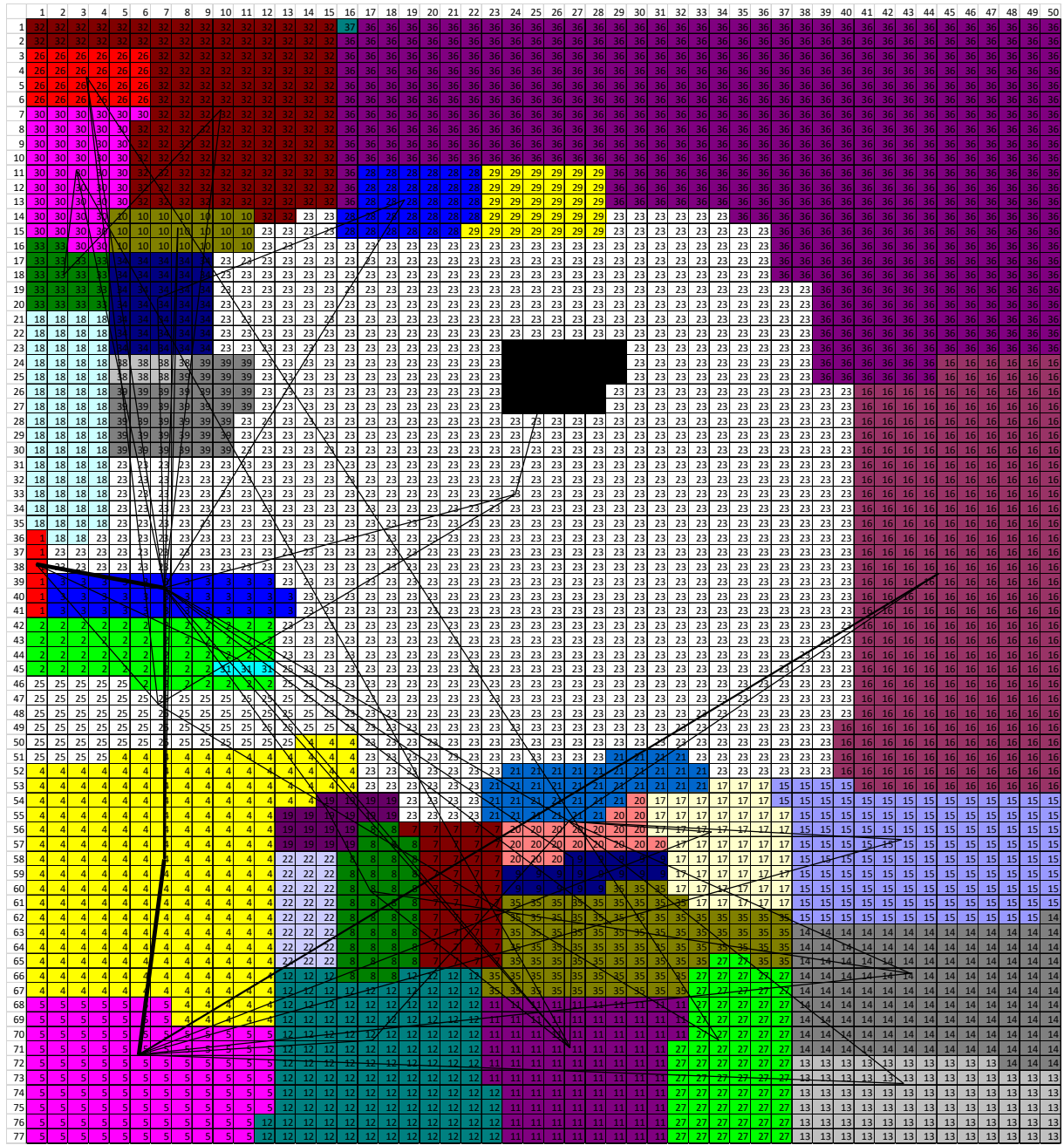


Figure F-3 Current layout with weighbridge moved CRAFT input

Table F-2 Current layout with weighbridge moved switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	2 and 1	12,027,931	6	23 and 2	10,934,028
2	16 and 15	11,764,384	7	12 and 5	10,627,599
3	16 and 35	11,371,268	8	5 and 22	10,164,680
4	16 and 7	11,139,447	9	5 and 19	9,870,162
5	16 and 8	10,979,659	10	16 and 20	10,264,452

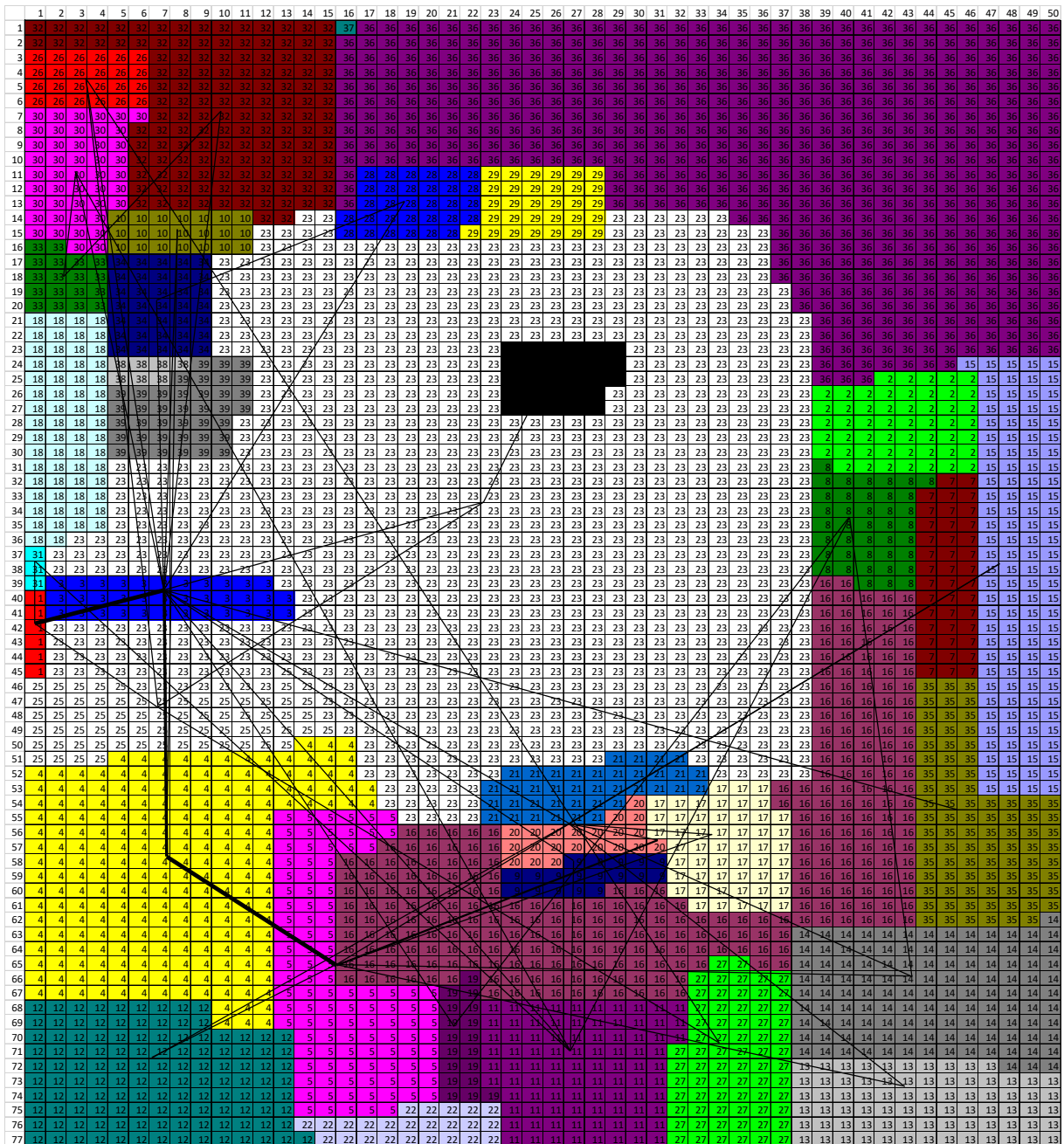


Figure F-4 Current layout weighbridge moved CRAFT output

### F.3 Greenfield CRAFT

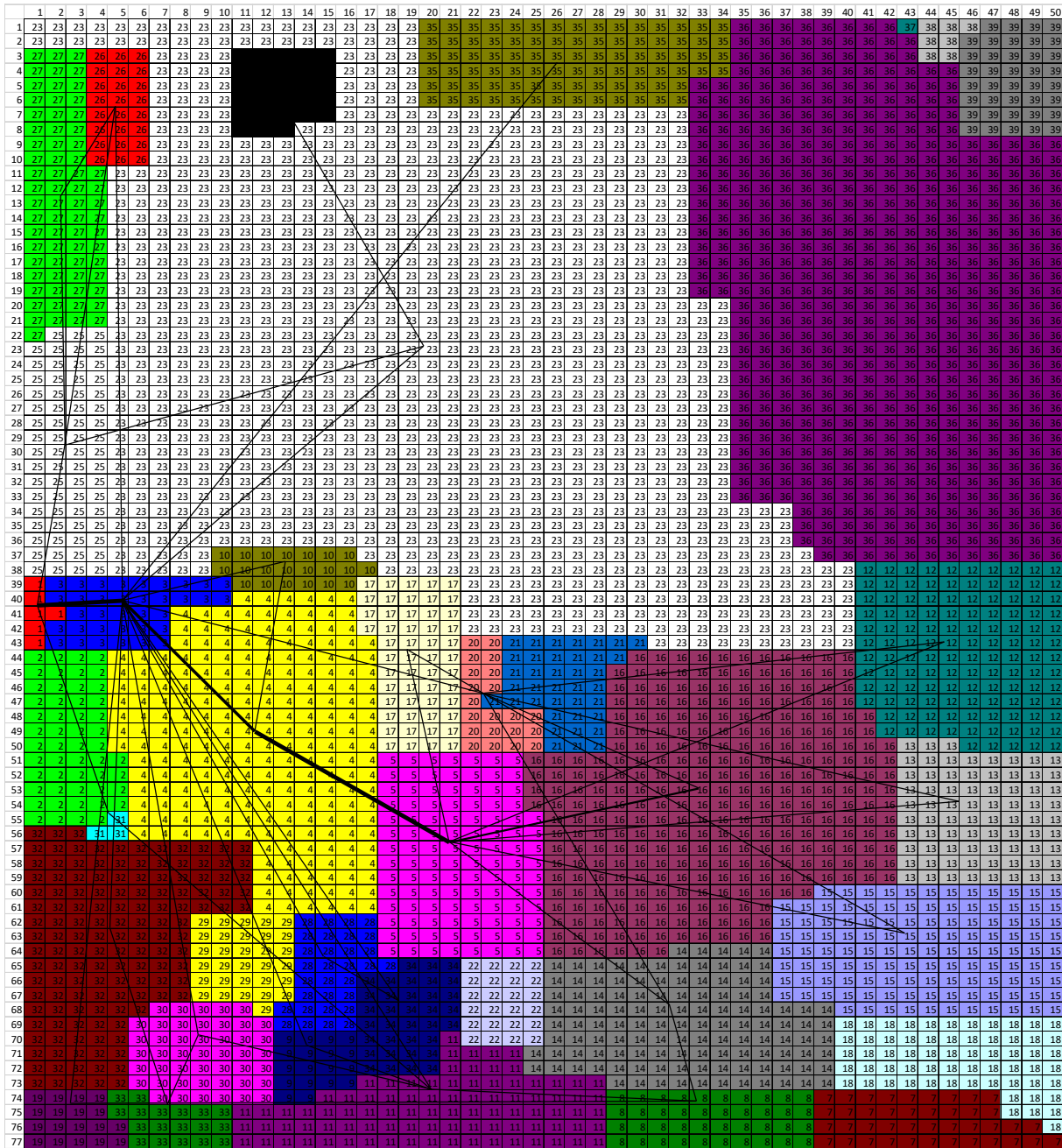


Figure F-5 Greenfield CRAFT input

Table F-3 Greenfield switches and new layout cost

Iteration	Switch departments	Layout Cost
1	16 and 21	8,702,610
2	23 and 10	8,951,888

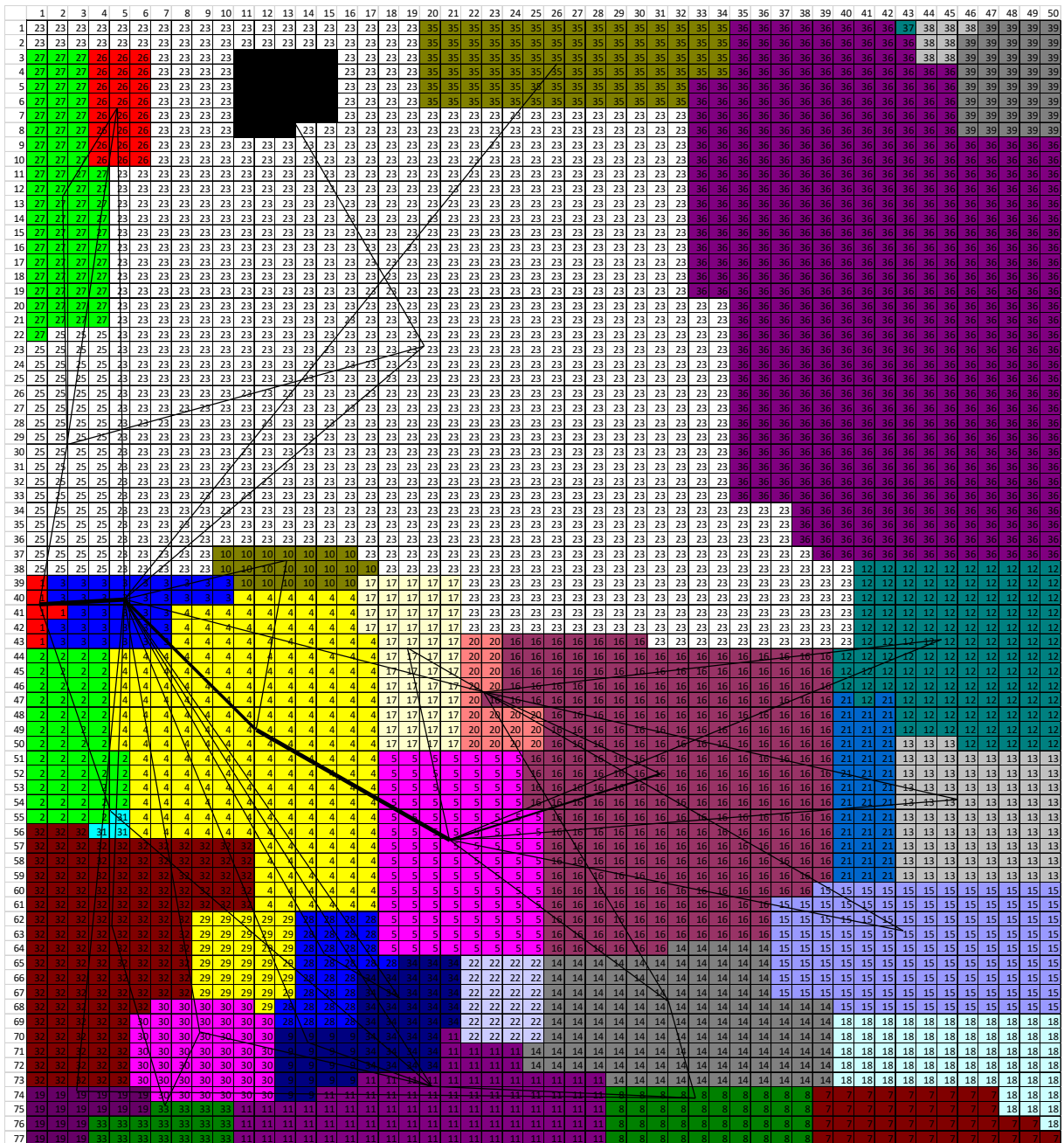


Figure F-6 Greenfield CRAFT output

## F.4 Layout option 1 CRAFT

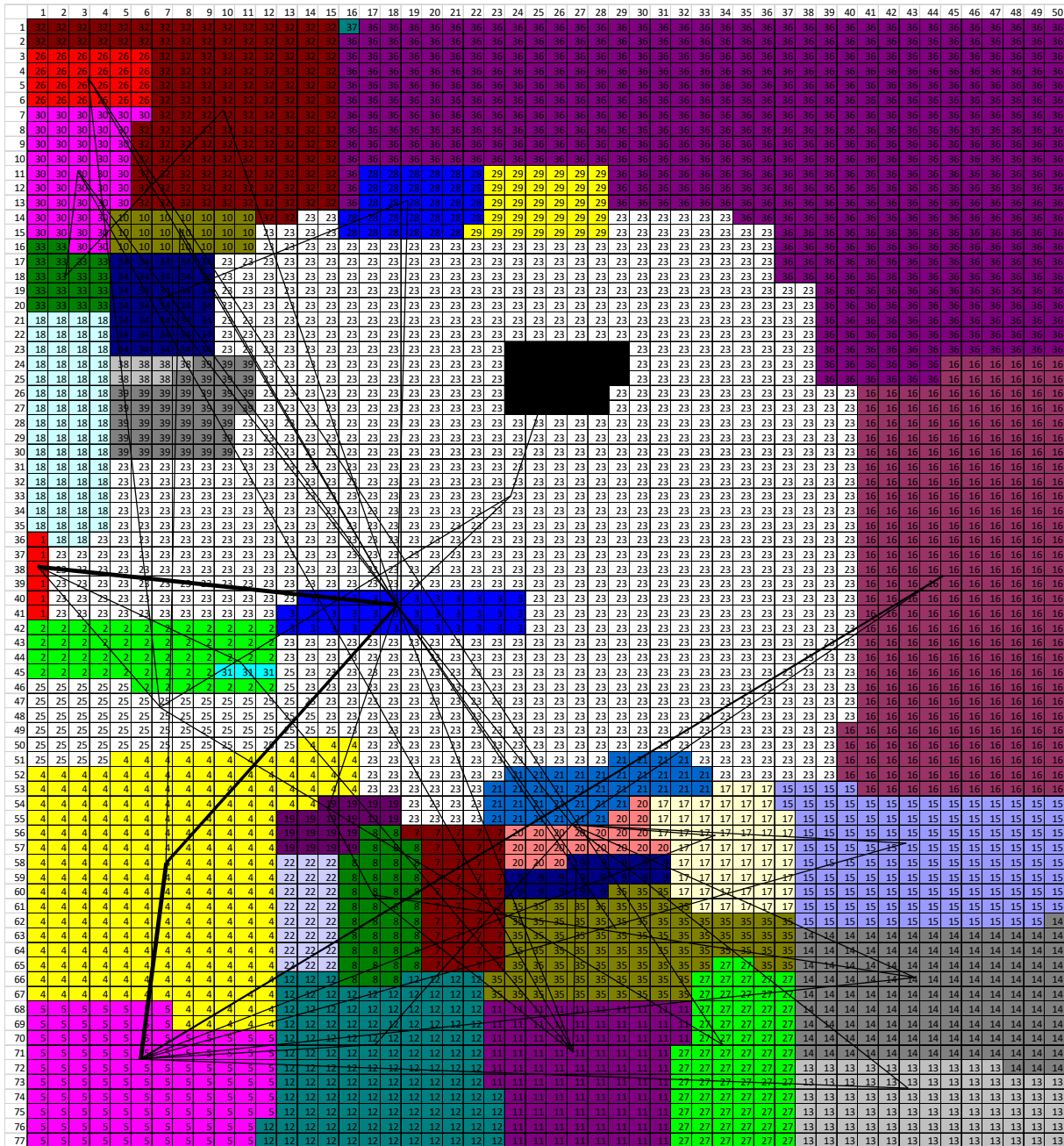


Figure F-7 Layout option 1 CRAFT input

Table F-4 Layout option 1 switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	16 and 15	13,664,820	7	30 and 33	12,461,653
2	16 and 35	13,266,606	8	18 and 30	12,331,837
3	16 and 12	12,797,393	9	15 and 35	12,283,178
4	17 and 9	12,727,724	10	15 and 27	12,217,206
5	14 and 27	12,573,688	11	25 and 31	12,234,010
6	17 and 20	12,536,459			

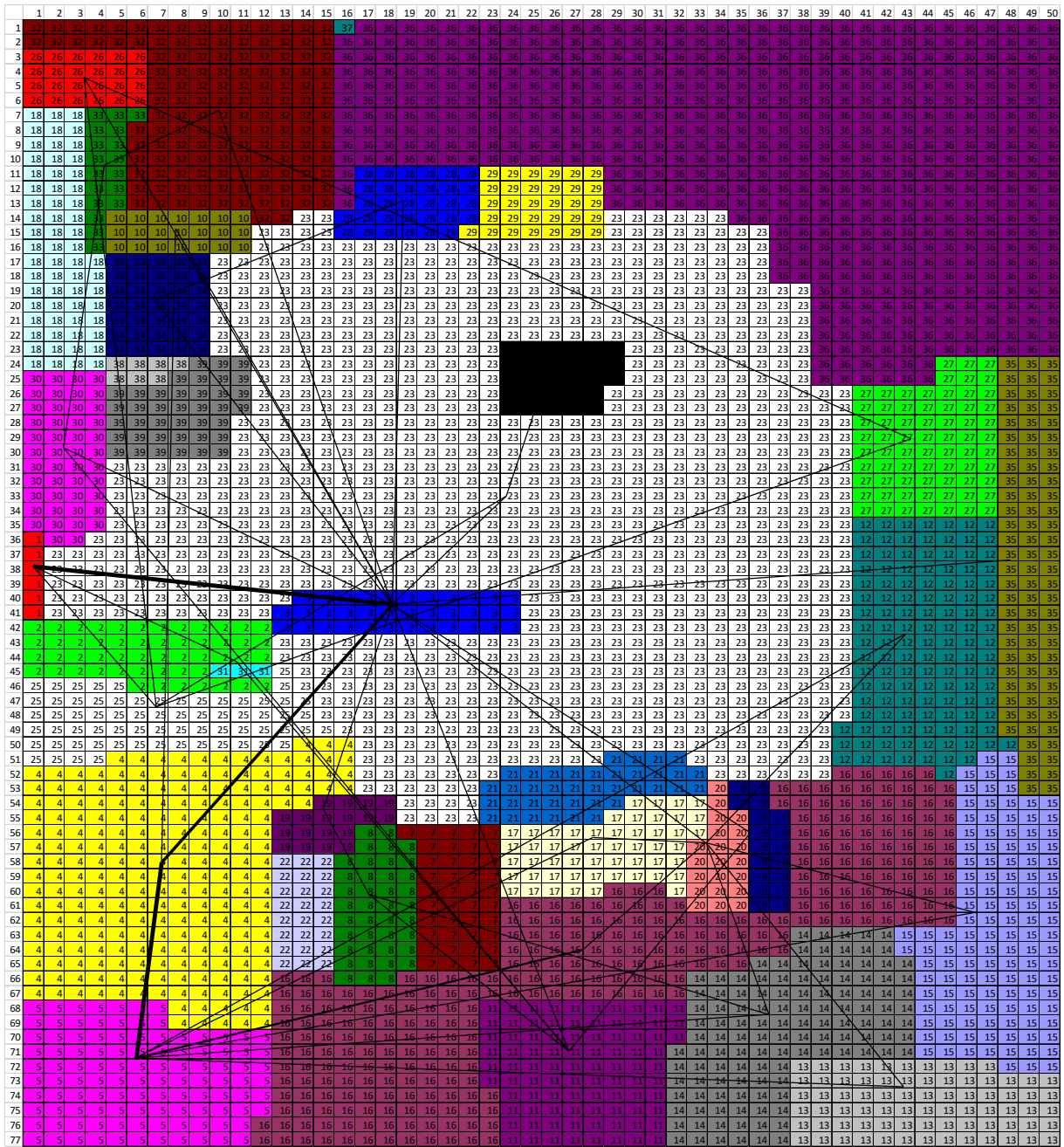


Figure F-8 Layout option 1 CRAFT output

## F.5 Layout option 2 CRAFT

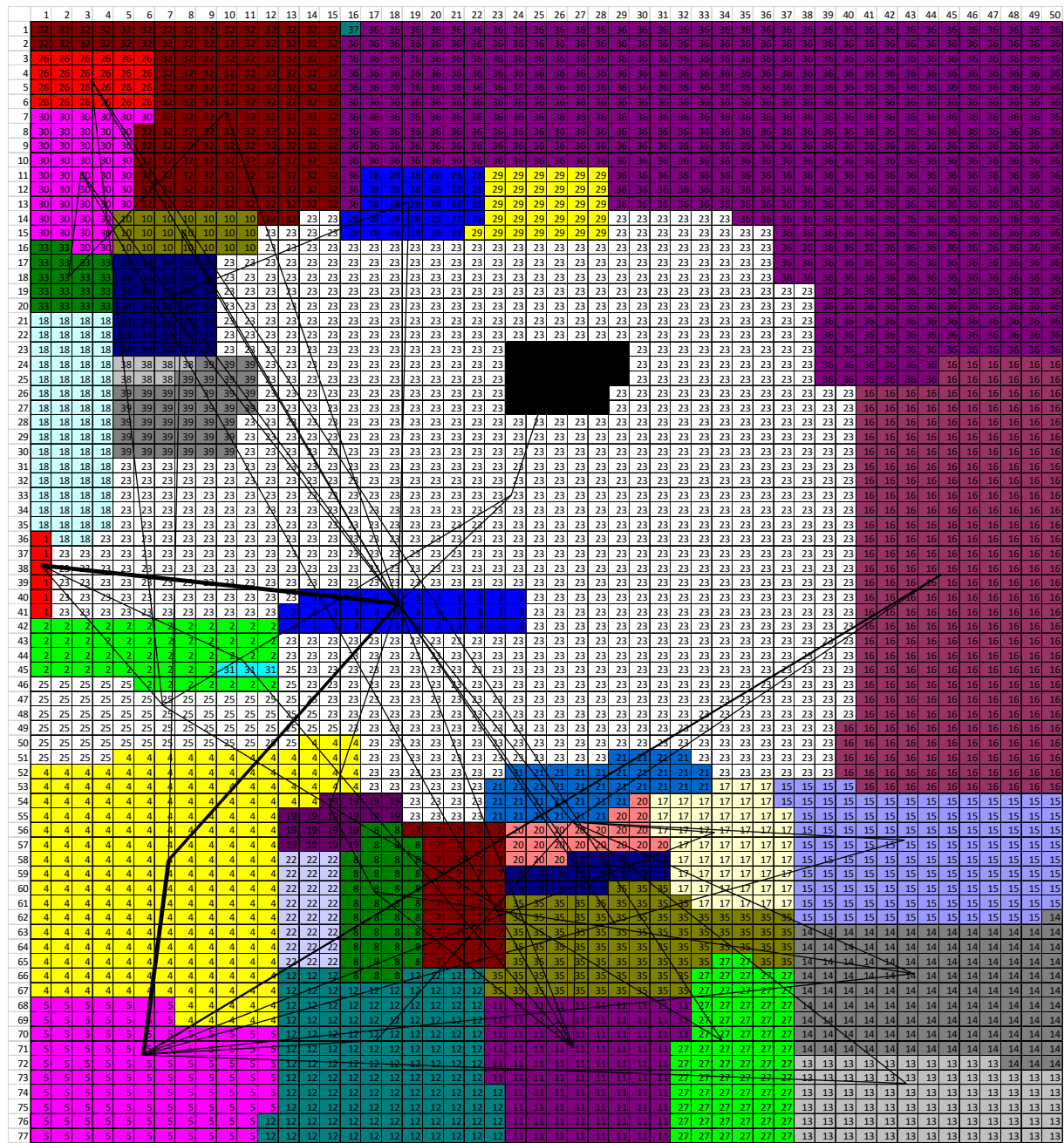


Figure F-9 Layout option 2 CRAFT input

Table F-5 Layout option 2 switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	16 and 15	13,664,820	5	12 and 5	12,568,569
2	16 and 35	13,266,606	6	5 and 22	12,105,652
3	16 and 7	13,034,788	7	5 and 19	11,810,426
4	16 and 8	12,875,000	8	16 and 20	12,173,248

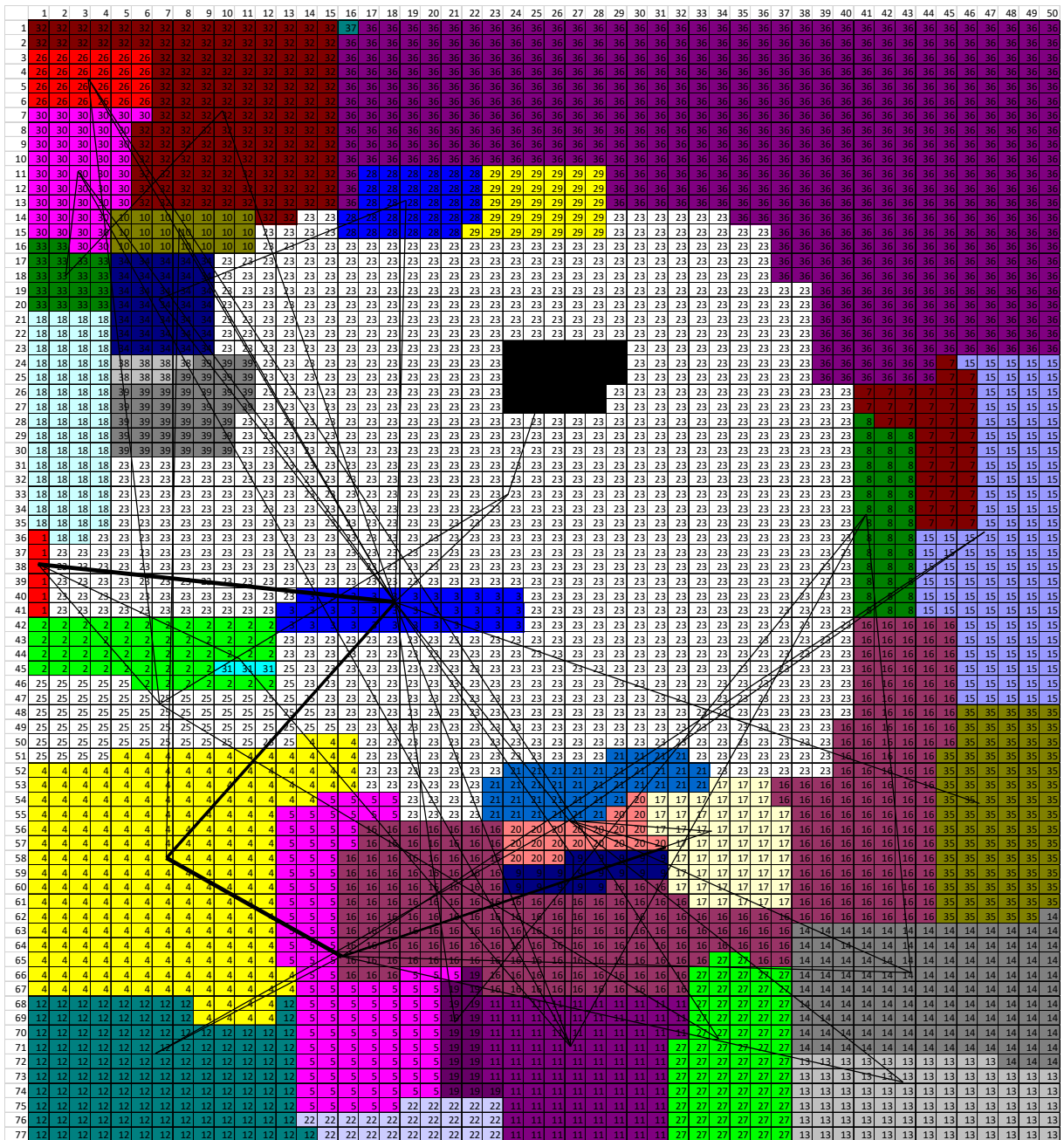


Figure F-10 Layout option 2 CRAFT output

## F.6 Equal size departments width 5

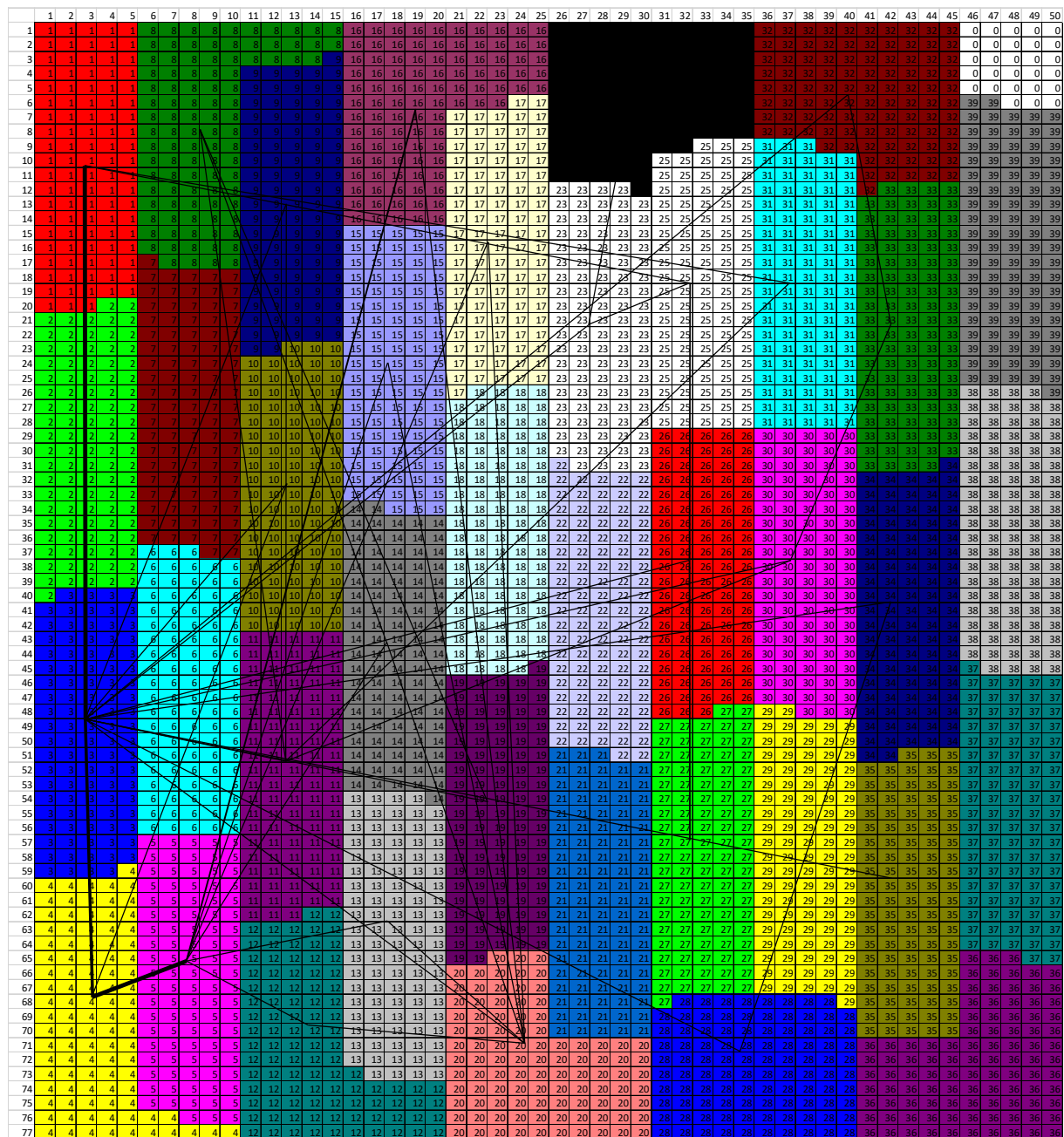


Figure F-11 Equal department size width 5 CRAFT input

Table F-6 Equal department size width 5 switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	1 and 6	16,500,899	19	16 and 17	8,263,790
2	11 and 16	13,398,609	20	23 and 24	8,219,570
3	17 and 19	11,565,976	21	14 and 27	8,196,446
4	17 and 20	10,750,492	22	8 and 29	8,098,262
5	18 and 25	10,253,271	23	19 and 35	8,037,992
6	13 and 17	9,991,262	24	27 and 28	8,017,218
7	15 and 28	9,759,279	25	29 and 34	7,989,779

8	8 and 22	9,528,753	26	26 and 27	7,973,843
9	7 and 23	9,340,755	27	12 and 15	7,958,900
10	2 and 24	9,147,853	28	10 and 30	7,944,015
11	10 and 25	9,002,780	29	9 and 11	7,938,044
12	7 and 32	8,860,376	30	9 and 22	7,896,693
13	19 and 31	8,722,841	31	27 and 34	7,892,778
14	15 and 21	8,628,563	32	26 and 31	7,888,688
15	19 and 34	8,561,785	33	22 and 27	7,879,136
16	8 and 30	8,503,323	34	22 and 35	7,873,965
17	14 and 30	8,371,113	35	12 and 13	7,870,982
18	18 and 33	8,314,901			

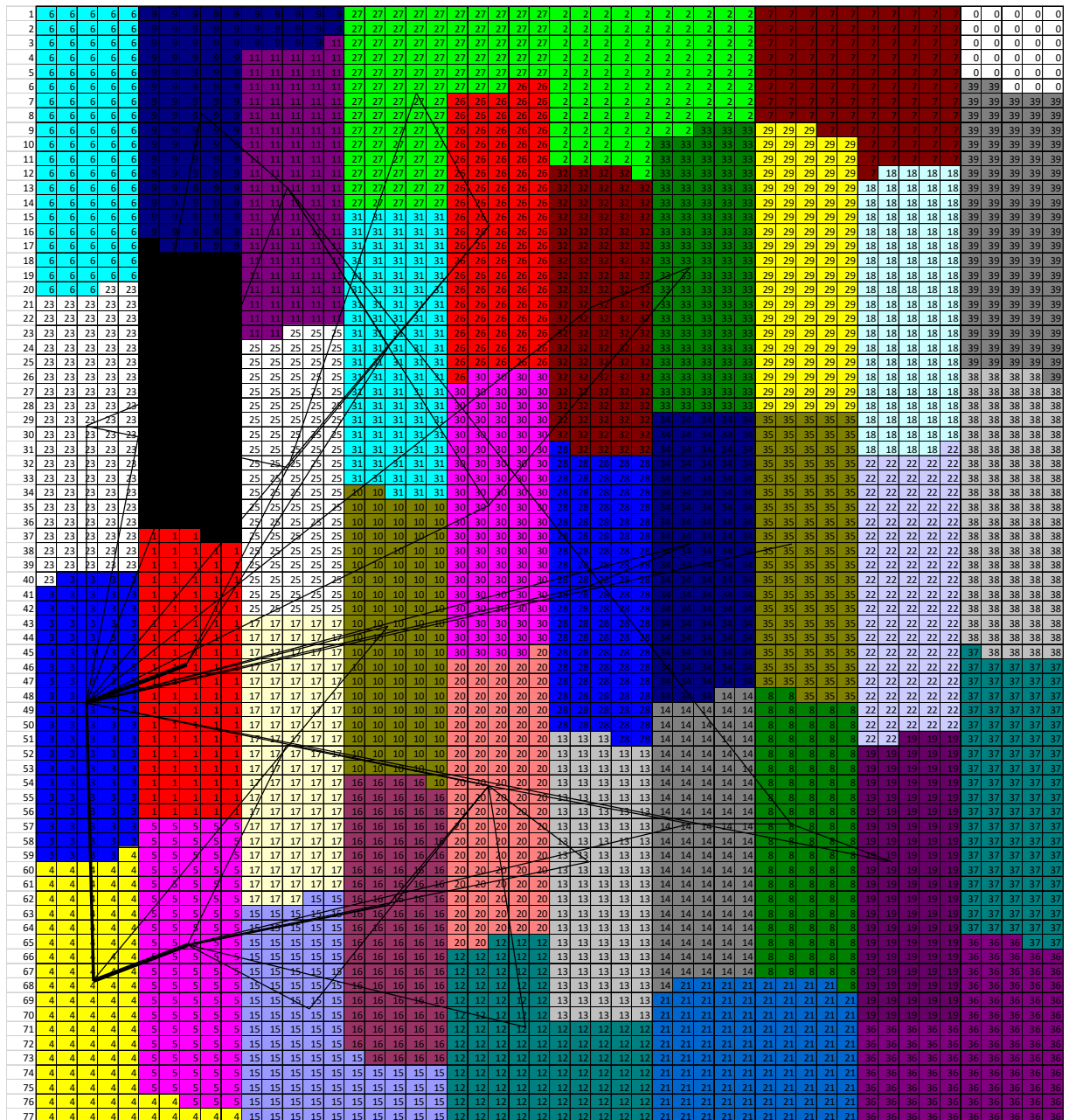


Figure F-12 Equal department size width 5 CRAFT output

## F.7 Equal size departments width 7

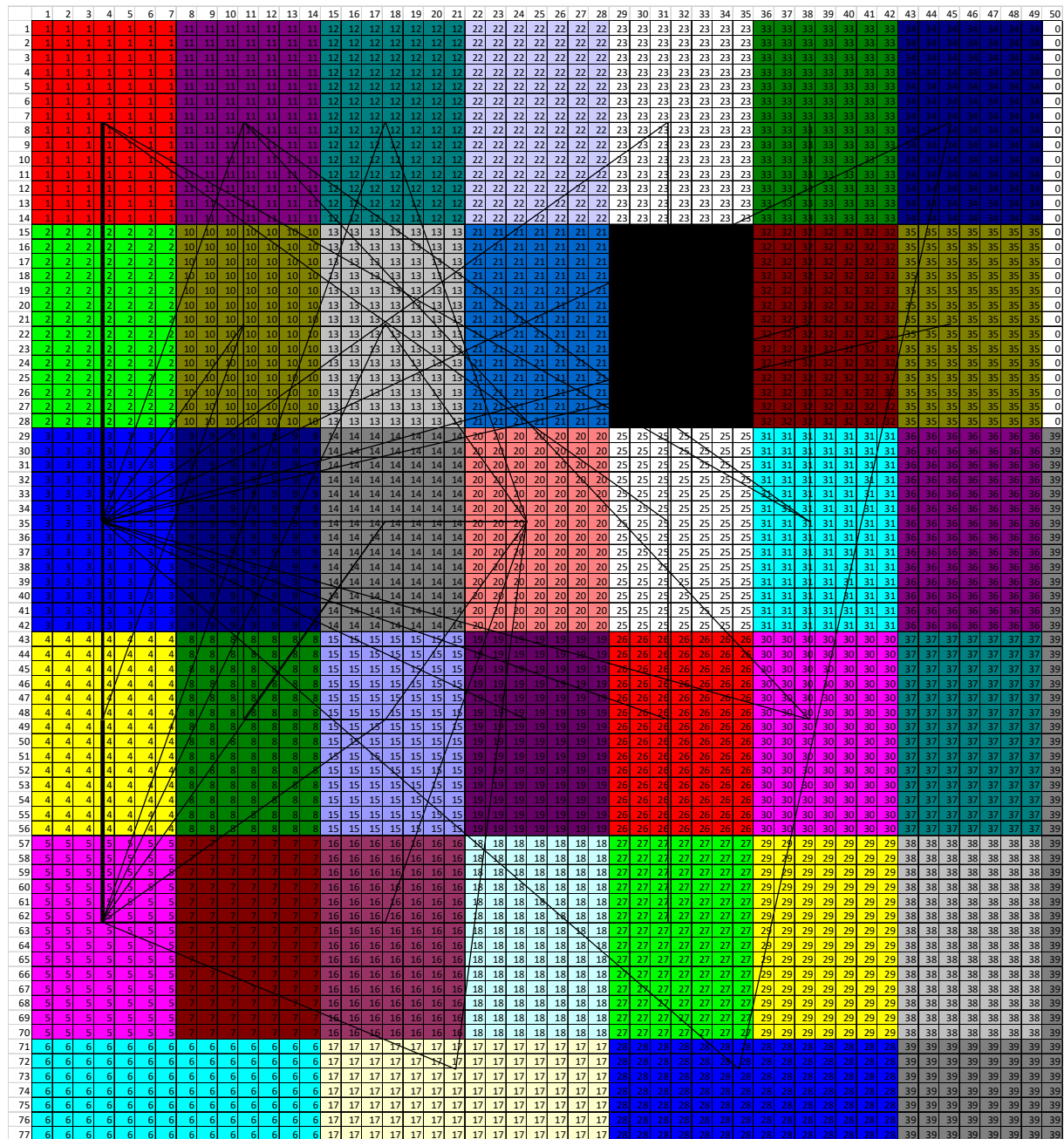


Figure F-13 Equal department size width 7 CRAFT input

Table F-7 Equal department size width 7 switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	1 and 9	12,553,597	13	17 and 20	7,958,361
2	5 and 8	11,783,563	14	8 and 14	7,864,864
3	17 and 19	10,891,830	15	12 and 18	7,789,944
4	15 and 16	10,347,553	16	7 and 13	7,747,503
5	21 and 23	9,842,497	17	22 and 34	7,710,043
6	2 and 28	9,410,978	18	23 and 30	7,684,851
7	12 and 31	9,027,230	19	33 and 35	7,657,936

8	13 and 30	8,707,090	20	7 and 26	7,644,449
9	14 and 25	8,439,050	21	7 and 35	7,623,157
10	8 and 26	8,233,901	22	10 and 28	7,614,631
11	8 and 20	8,135,350	23	27 and 37	7,609,195
12	12 and 19	8,037,163	24	13 and 15	7,605,662

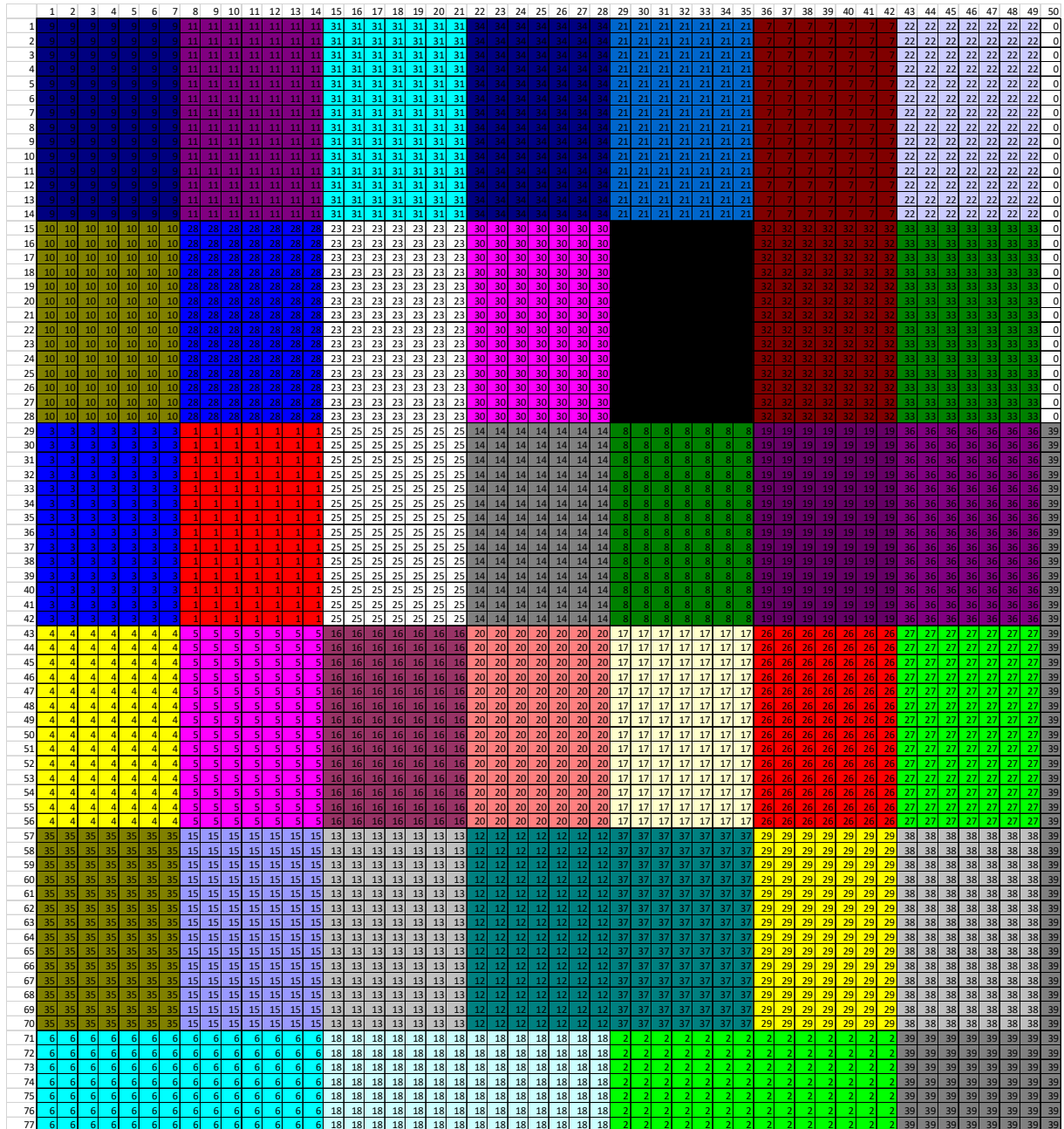


Figure F-14 Equal department size width 7 CRAFT output

## F.8 Equal size departments width 14

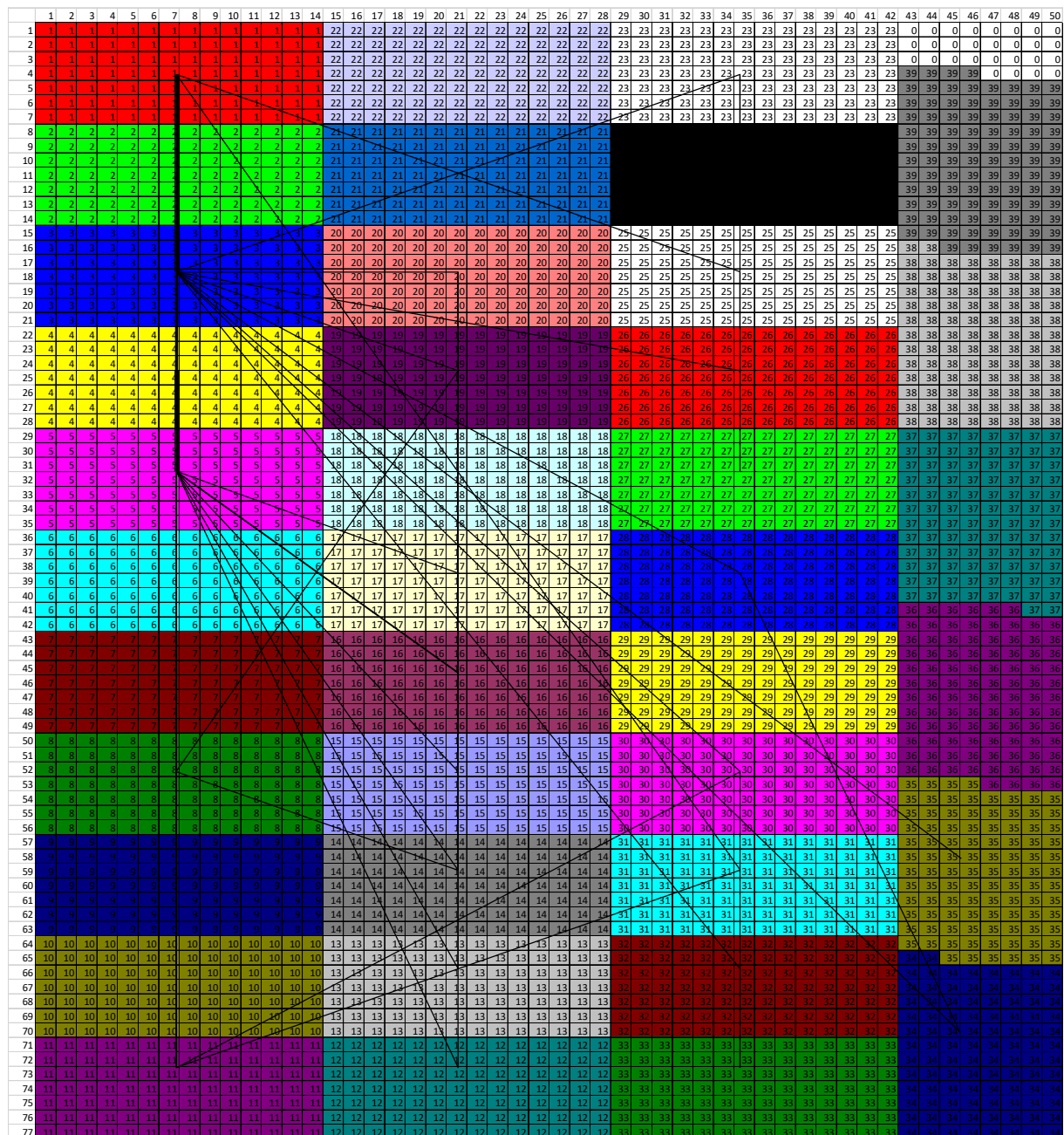


Figure F-15 Equal department size width 14 CRAFT input

Table F-8 Equal department size width 14 switches and new layout cost

Iteration	Switch departments	Layout Cost	Iteration	Switch departments	Layout Cost
1	15 and 20	11,729,186	17	6 and 19	7,745,508
2	1 and 2	10,591,798	18	6 and 33	7,699,735
3	2 and 25	10,152,758	19	29 and 32	7,618,712
4	21 and 23	9,726,050	20	33 and 34	7,553,634
5	10 and 19	9,308,472	21	27 and 32	7,513,745
6	15 and 30	9,020,190	22	9 and 31	7,475,646
7	8 and 13	8,844,387	23	2 and 35	7,439,370

8	19 and 31	8,644,719	24	12 and 14	7,416,589
9	6 and 12	8,491,676	25	26 and 33	7,397,966
10	18 and 28	8,348,121	26	32 and 35	7,380,022
11	7 and 15	8,252,946	27	22 and 26	7,362,949
12	11 and 31	8,175,972	28	21 and 27	7,331,241
13	18 and 34	8,113,812	29	22 and 34	7,299,852
14	12 and 16	8,059,194	30	10 and 30	7,295,070
15	12 and 20	7,839,643	31	13 and 15	7,291,449
16	22 and 24	7,786,027			

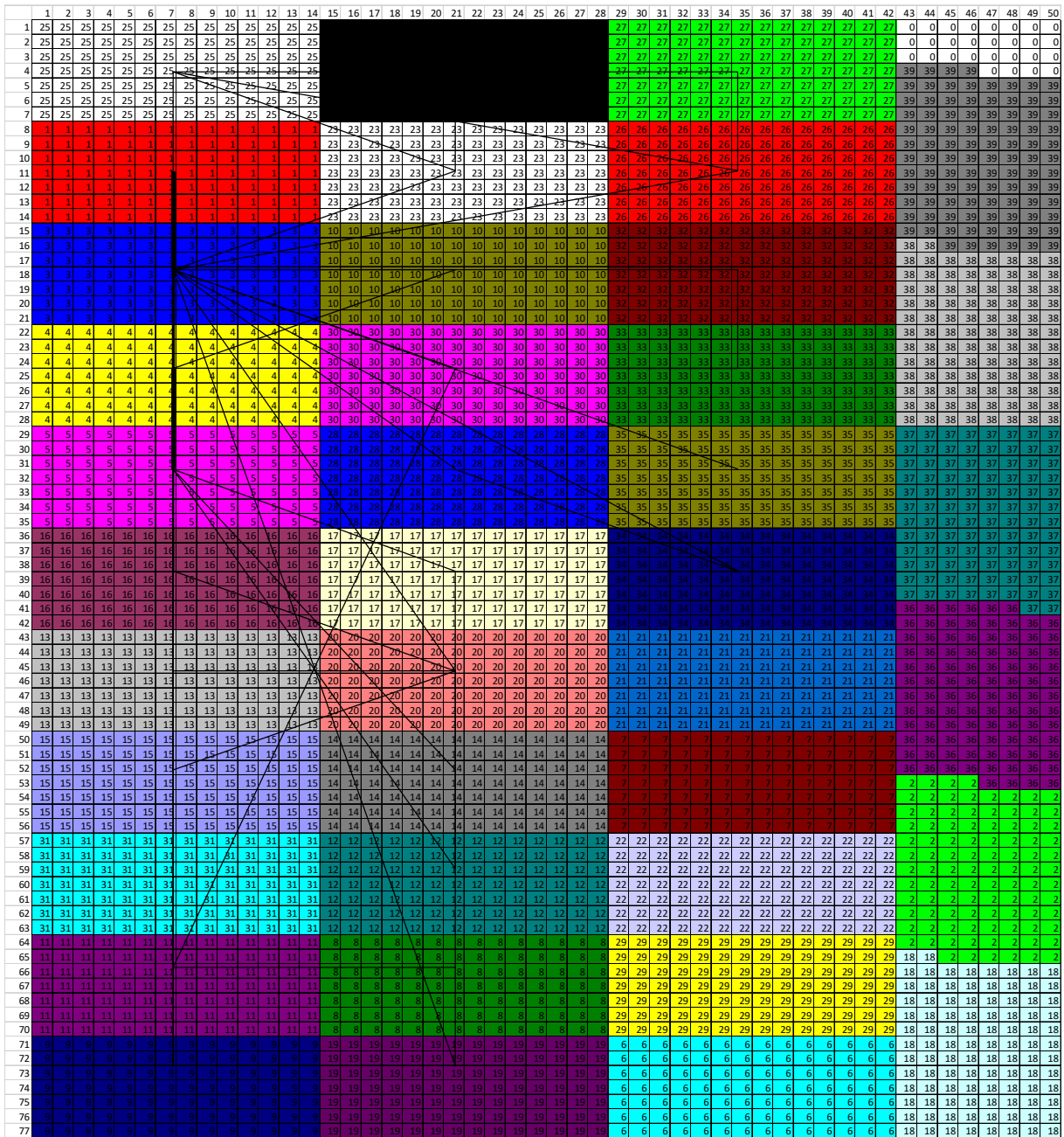


Figure F-16 Equal department size width 14 CRAFT output

## G. Simulation results for vehicles

In this appendix we show the result tables from the simulations. The shown tables contain data collected over five simulation runs covering two years each run, data can be seen as equalling ten years of operation.

\* All values in this appendix are indexed.

### G.1 Current situation

Table G-1 Simulation results current layout

Row Labels	Count of Vehicle	Average of Waiting Time	Average of Time On Terrain	Variance of Waiting Time	Variance of Time On Terrain	Max of Waiting Time Calc	Max of Time On Terrain	Sum of Driven Distance
Metal_FMP_Car_Incoming	557	360	1,392	250,829	251,045	5,459	6,493	58,454
Metal_FWB_Car_Incoming	48,934	1,236	4,269	1,095,969	1,652,206	17,647	22,848	7,976,231
Metal_NFMP_Car_Incoming	66,373	363	1,398	201,461	201,681	8,620	9,651	6,969,195
Metal_NFWB_Car_Incoming	9,816	718	3,457	561,303	1,206,677	18,685	19,736	1,599,927
MetalF_Truck_Incoming	64,724	1,222	4,260	1,081,595	1,629,528	20,844	24,029	10,549,963
MetalF_Truck_Outgoing	8,570	832	7,430	763,350	2,332,333	13,777	23,475	1,396,951
MetalNF_Truck_Incoming	14,237	703	3,452	524,795	1,207,254	13,625	17,416	2,320,610
MetalNF_Truck_Outgoing	3,513	680	7,934	667,674	4,374,610	14,838	25,529	572,630
Paper_Car_Archive	18,755	331	1,187	205,868	206,087	7,357	8,213	1,969,268
Paper_Car_Incoming	37,173	571	2,347	214,192	223,310	7,993	9,742	9,962,340
Paper_Truck_Archive	5,157	442	3,677	167,101	920,618	6,490	10,639	1,196,378
Paper_Truck_HQ	21,278	422	1,368	131,578	141,434	6,226	7,140	3,787,423
Paper_Truck_Incoming	264,532	900	2,819	405,814	491,675	9,572	11,395	38,886,222
Paper_Truck_Outgoing	35,620	363	5,983	92,699	2,252,312	5,526	162,972	5,125,736
Plastic_Car_Incoming	5,034	557	1,770	199,047	211,499	6,534	7,823	1,583,290
Plastic_Truck_Incoming	18,207	557	1,770	211,590	226,357	7,618	8,869	5,739,272
Plastic_Truck_Outgoing	2,877	554	1,591	202,744	219,214	5,787	6,677	908,675
Waste_Car_Incoming	4,020	577	1,600	221,991	235,411	6,815	7,806	956,750
Waste_Truck_Incoming	45,283	557	1,585	201,068	211,605	7,820	9,259	10,777,390
Waste_Truck_Outgoing	11,160	533	1,568	183,368	196,688	7,193	8,324	2,656,168
WEEE_Car_Incoming	1,269	419	1,732	151,024	158,085	3,885	5,268	159,855
WEEE_Truck_Incoming	3,153	431	1,746	162,597	165,243	6,654	8,019	397,238
WEEE_Truck_Outgoing	319	510	1,614	222,835	245,147	5,063	6,382	86,869
Wood_Car_Incoming	2,605	847	3,909	556,981	1,011,758	12,713	17,943	995,022
Wood_Truck_Incoming	35,778	779	3,865	445,214	810,441	12,488	14,471	13,667,284
Wood_Truck_Outgoing	5,980	759	5,737	369,324	1,560,415	8,585	15,775	2,284,410
Grand Total	734,923	768	2,994	466,444	1,367,015	20,844	162,972	132,583,549

### G.2 Current layout with weighbridge moved

Table G-2 Simulation results current layout with weighbridge moved vehicle data

Row Labels	Count of Vehicle	Average of Waiting Time	Average of Time On Terrain	Variance of Waiting Time	Variance of Time On Terrain	Max of Waiting Time Calc	Max of Time On Terrain	Sum of Driven Distance
Metal_FMP_Car_Incoming	557	100	1,632	12,499	22,889	905	3,003	57,340
Metal_FWB_Car_Incoming	48,934	932	3,976	995,447	1,554,977	17,568	22,822	8,318,768
Metal_NFMP_Car_Incoming	66,373	100	1,632	14,934	23,047	3,229	4,747	6,836,449
Metal_NFWB_Car_Incoming	9,816	416	3,164	483,690	1,127,819	17,308	18,274	1,668,635
MetalF_Truck_Incoming	64,727	923	3,970	980,709	1,533,146	20,964	24,052	11,003,527
MetalF_Truck_Outgoing	8,570	522	7,143	674,580	2,236,662	14,035	22,936	1,456,943
MetalNF_Truck_Incoming	14,237	404	3,164	434,636	1,116,547	12,362	17,398	2,420,268
MetalNF_Truck_Outgoing	3,513	396	7,662	583,548	4,284,879	14,911	25,617	597,222

Paper_Car_Archive	18,755	243	1,603	108,706	116,388	5,174	6,399	1,969,268
Paper_Car_Incoming	37,173	94	1,828	20,917	29,877	5,760	7,460	8,921,498
Paper_Truck_Archive	5,157	108	3,273	54,176	831,563	5,737	10,047	990,106
Paper_Truck_HQ	21,278	85	970	23,012	32,579	5,210	6,261	2,936,317
Paper_Truck_Incoming	264,535	636	2,493	308,233	392,327	7,234	9,733	27,776,180
Paper_Truck_Outgoing	35,620	59	5,681	7,943	1,446,661	4,199	17,691	5,216,341
Plastic_Car_Incoming	5,034	64	1,242	11,445	21,421	2,989	3,944	1,450,432
Plastic_Truck_Incoming	18,210	62	1,239	8,096	19,279	3,012	4,392	5,224,893
Plastic_Truck_Outgoing	2,877	59	1,049	5,910	15,722	1,623	2,619	829,167
Waste_Car_Incoming	4,020	59	1,040	6,039	15,951	993	2,288	844,192
Waste_Truck_Incoming	45,286	64	1,055	10,686	19,663	5,098	5,954	9,510,077
Waste_Truck_Outgoing	11,160	59	1,049	10,000	19,203	3,985	4,946	2,343,678
WEEE_Car_Incoming	1,269	94	1,617	14,293	22,385	1,360	2,901	130,675
WEEE_Truck_Incoming	3,153	91	1,620	13,639	20,489	1,512	3,033	324,726
WEEE_Truck_Outgoing	319	59	1,113	5,503	17,272	697	1,899	77,926
Wood_Car_Incoming	2,605	331	3,364	256,530	624,497	8,371	10,627	922,089
Wood_Truck_Incoming	35,778	314	3,358	261,473	649,103	11,658	15,204	12,665,493
Wood_Truck_Outgoing	5,980	314	5,253	267,146	1,533,336	8,969	14,770	2,116,966
Grand Total	734,935	448	2,701	346,326	1,174,573	20,964	25,617	116,609,174

### G.3 Greenfield layout

Table G-3 Simulation results greenfield vehicle data

Row Labels	Count of Vehicle	Average of Waiting Time	Average of Time On Terrain	Variance of Waiting Time	Variance of Time On Terrain	Max of Waiting Time Calc	Max of Time On Terrain	Sum of Driven Distance
Metal_FMP_Car_Incoming	557	94	1,673	10,352	17,768	691	2,496	17,685
Metal_FWB_Car_Incoming	48,934	941	4,029	1,005,183	1,568,605	17,832	22,968	15,697,135
Metal_NFMP_Car_Incoming	66,373	73	1,667	8,623	16,862	1,573	3,159	1,644,454
Metal_NFWB_Car_Incoming	9,816	425	3,220	495,768	1,138,161	17,498	18,409	1,420,514
MetalF_Truck_Incoming	64,724	932	4,023	986,803	1,536,835	21,228	24,360	20,589,087
MetalF_Truck_Outgoing	8,570	530	7,196	681,073	2,235,151	14,187	22,637	1,554,954
MetalNF_Truck_Incoming	14,237	413	3,214	439,992	1,119,503	12,368	17,882	2,008,292
MetalNF_Truck_Outgoing	3,513	413	7,726	607,152	4,299,690	14,911	25,664	494,915
Paper_Car_Archive	18,755	62	1,401	7,700	16,478	4,533	5,913	402,901
Paper_Car_Incoming	37,173	94	1,629	18,433	26,868	4,937	6,680	1,175,616
Paper_Truck_Archive	5,157	97	3,255	35,822	811,317	5,737	10,041	172,161
Paper_Truck_HQ	21,278	64	982	7,366	16,382	4,776	5,667	470,403
Paper_Truck_Incoming	264,532	357	1,928	129,922	197,913	6,976	8,415	32,234,931
Paper_Truck_Outgoing	35,620	64	4,978	10,109	585,540	3,132	14,263	792,832
Plastic_Car_Incoming	5,034	56	1,028	5,954	16,352	1,371	2,203	96,596
Plastic_Truck_Incoming	18,207	53	1,034	6,827	17,721	4,506	5,347	334,457
Plastic_Truck_Outgoing	2,877	62	856	6,877	17,258	1,289	2,145	59,048
Waste_Car_Incoming	4,020	59	929	5,517	15,711	1,330	2,186	79,907
Waste_Truck_Incoming	45,283	59	932	6,241	15,218	3,258	4,076	907,207
Waste_Truck_Outgoing	11,160	59	932	6,127	15,239	1,617	2,640	219,703
WEEE_Car_Incoming	1,269	64	1,647	7,855	16,147	1,108	2,707	28,269
WEEE_Truck_Incoming	3,153	73	1,661	8,321	16,528	1,222	2,666	77,844
WEEE_Truck_Outgoing	319	41	999	3,446	13,912	557	1,694	4,577
Wood_Car_Incoming	2,605	308	2,930	253,474	650,519	8,122	11,055	274,254
Wood_Truck_Incoming	35,778	302	2,927	261,995	646,897	12,300	16,880	3,678,052
Wood_Truck_Outgoing	5,980	290	4,861	233,843	1,496,963	9,150	17,577	593,835
Grand Total	734,923	340	2,420	274,251	1,066,423	21,228	25,664	85,029,628

## G.4 Layout option 1

Table G-4 Simulation results layout option 1 vehicle data

Row Labels	Count of Vehicle	Average of Waiting Time	Average of Time On Terrain	Variance of Waiting Time	Variance of Time On Terrain	Max of Waiting Time Calc	Max of Time On Terrain	Sum of Driven Distance
Metal_FMP_Car_Incoming	557	363	1,395	209,782	210,014	4,694	5,728	58,454
Metal_FWB_Car_Incoming	48,934	1,236	4,269	1,092,776	1,645,977	17,483	22,625	7,976,231
Metal_NFMP_Car_Incoming	66,373	363	1,395	203,125	203,342	8,028	9,060	6,969,195
Metal_NFWB_Car_Incoming	9,816	724	3,466	588,083	1,239,871	18,389	19,569	1,599,927
MetalF_Truck_Incoming	64,724	1,222	4,260	1,088,967	1,640,109	20,522	23,642	10,549,963
MetalF_Truck_Outgoing	8,570	832	7,436	763,699	2,333,965	13,803	23,302	1,396,951
MetalNF_Truck_Incoming	14,237	703	3,449	526,457	1,215,121	13,317	17,340	2,320,610
MetalNF_Truck_Outgoing	3,513	686	7,937	663,607	4,350,684	15,131	25,529	572,630
Paper_Car_Archive	18,755	319	1,175	187,412	187,617	8,069	8,928	1,969,268
Paper_Car_Incoming	37,173	571	2,344	222,451	230,931	8,728	10,337	9,962,340
Paper_Truck_Archive	5,157	413	3,642	140,959	902,730	5,755	10,501	1,196,378
Paper_Truck_HQ	21,278	404	1,348	115,099	125,571	7,061	8,239	3,787,423
Paper_Truck_Incoming	264,532	902	2,819	405,978	492,448	9,051	10,970	38,886,222
Paper_Truck_Outgoing	35,620	363	5,716	93,394	1,893,597	6,484	160,640	5,123,931
Plastic_Car_Incoming	5,034	560	1,770	208,241	224,543	7,149	8,230	1,584,521
Plastic_Truck_Incoming	18,207	542	1,758	193,931	207,048	7,483	8,632	5,726,966
Plastic_Truck_Outgoing	2,877	539	1,570	195,217	205,812	6,428	7,518	906,390
Waste_Car_Incoming	4,020	589	1,550	247,198	255,402	7,055	7,896	771,832
Waste_Truck_Incoming	45,283	554	1,518	197,954	209,357	7,360	8,248	8,694,365
Waste_Truck_Outgoing	11,160	536	1,500	193,143	204,684	7,284	8,444	2,142,791
WEEE_Car_Incoming	1,269	407	1,723	148,100	153,087	4,717	5,989	159,855
WEEE_Truck_Incoming	3,153	451	1,761	163,805	167,101	4,975	6,132	397,238
WEEE_Truck_Outgoing	319	583	1,694	200,178	211,095	4,333	5,133	86,869
Wood_Car_Incoming	2,605	815	3,961	538,388	898,435	9,813	13,197	995,022
Wood_Truck_Incoming	35,778	782	3,885	473,635	864,860	12,748	16,695	13,667,284
Wood_Truck_Outgoing	5,980	797	5,822	426,385	1,824,411	10,636	18,386	2,284,410
Grand Total	734,923	768	2,977	468,659	1,338,078	20,522	160,640	129,787,063

## G.5 Layout option 2

Table G-5 Simulation results layout option 2 vehicle data

Row Labels	Count of Vehicle	Average of Waiting Time	Average of Time On Terrain	Variance of Waiting Time	Variance of Time On Terrain	Max of Waiting Time Calc	Max of Time On Terrain	Sum of Driven Distance
Metal_FMP_Car_Incoming	557	381	1,412	269,736	269,912	5,886	6,918	58,454
Metal_FWB_Car_Incoming	48,934	1,236	4,272	1,095,709	1,655,564	17,779	22,957	7,976,231
Metal_NFMP_Car_Incoming	66,373	363	1,395	203,459	203,673	9,719	10,750	6,969,195
Metal_NFWB_Car_Incoming	9,816	715	3,452	570,278	1,213,187	18,544	19,517	1,599,927
MetalF_Truck_Incoming	64,724	1,225	4,263	1,093,110	1,643,232	20,284	23,991	10,549,963
MetalF_Truck_Outgoing	8,570	835	7,436	763,546	2,327,721	13,683	23,176	1,396,951
MetalNF_Truck_Incoming	14,237	703	3,449	526,424	1,214,356	13,162	17,416	2,320,610
MetalNF_Truck_Outgoing	3,513	694	7,943	671,175	4,350,921	15,362	25,799	572,630
Paper_Car_Archive	18,755	322	1,181	196,688	196,896	7,387	8,245	1,969,268
Paper_Car_Incoming	37,173	574	2,353	223,011	233,169	9,089	10,944	9,962,340
Paper_Truck_Archive	5,157	425	3,657	144,827	907,863	5,746	11,336	1,196,378
Paper_Truck_HQ	21,278	410	1,351	115,419	126,025	6,959	8,137	3,787,423
Paper_Truck_Incoming	264,532	902	2,822	412,298	496,313	10,021	11,787	38,886,222
Paper_Truck_Outgoing	35,620	363	5,933	94,803	2,193,023	5,848	164,361	5,126,228
Plastic_Car_Incoming	5,034	557	1,773	194,329	212,829	5,722	6,921	1,582,587
Plastic_Truck_Incoming	18,207	545	1,761	197,749	212,144	7,258	8,386	5,742,964
Plastic_Truck_Outgoing	2,877	554	1,579	205,414	215,496	6,701	7,893	903,401
Waste_Car_Incoming	4,020	577	1,606	220,831	231,789	7,082	8,040	956,750
Waste_Truck_Incoming	45,283	554	1,582	201,637	213,562	9,083	9,988	10,777,390
Waste_Truck_Outgoing	11,160	533	1,562	187,444	199,600	6,716	7,691	2,656,168
WEEE_Car_Incoming	1,269	440	1,752	176,790	182,252	6,036	7,480	159,855
WEEE_Truck_Incoming	3,153	428	1,740	146,368	150,558	5,201	6,686	397,238
WEEE_Truck_Outgoing	319	560	1,667	250,143	268,236	6,188	7,448	86,869
Wood_Car_Incoming	2,605	809	3,932	511,317	912,053	13,261	17,788	995,022
Wood_Truck_Incoming	35,778	791	3,891	478,490	888,543	16,593	19,145	13,667,284
Wood_Truck_Outgoing	5,980	794	5,810	441,446	1,720,150	10,085	17,445	2,284,410
Grand Total	734,923	771	2,994	472,114	1,370,660	20,284	164,361	132,581,756