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Data Gathering Method to Measure the Effects of Resource Input of on the Production Process

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July 2019

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Management Summary

0.1 Introduction

Rodepa is a recycling company which turns industrial plastic waste and consumers plastic waste into high-quality regranulate and regrind. They can wash the contaminated waste and turn it into a product that can be extruded. The company has 2 modern washing lines that cleans hard plastics and foil.

They recently started with producing regrind, from both foil and hard plastics. The profit per batch can be different, due to the variability in the resource input for the washing lines. This is dependent on the quality of the resource input itself and also depend on the supplier. There is currently a method missing with which you can measure the performance of the washing line. In this research, we will solve the question: "What is the production performance of a resource input during a production run?". With this information you can calculate the costs of production and also keep track of the production line performance. This gives a handle to compare the quality of freights with each other.

0.2 Approach

In order to understand the washing line, a full description of the washing lines was made. Also a research was conducted on the quality standards of resource inputs and also on the quality checks that are performed during the production process. International quality standards and quality test were gathered to get an good insight in the waste market and understand the challenges.
Then a plan is made to measure the inputs and outputs, with the help of the washing line description.

0.3 Execution

In order to measure the performance of a freight, the following is needed:

1. **Characterisation of Freight:** Quality standards on the resource input do not exists. With the help of the production manager a list with standard characteristics was made,

based on subjective grading, on which you can grade the input. With this list you can compare different resource inputs with each other.

2. **Measurement Plan for Washing Line:** The performance of a resource input on the washing deviates. With this plan you can measure the total output and inputs of the washing line.

3. **KPIs Tailored for Washing Line:** The information gathered during the measurement plan, have to be processed. Tailor made KPIs for the washing line are made to process the production data.

4. **Scoring:** In order to compare the different freight with each other, a scoring mechanism was made. This scoring mechanism is called the Freight Score. This is the added value, better known as the profit, per ton output product per hour produced. In this score we also take notice of the downtime that a production line has, due to a failure caused by the resource input.

5. **Ranking:** With this score a ranking, and finally a recommendation, can be made on the supplier. In the ranking system we will regard the seasonality of a resource input, the technical innovations that a supplier has and the overall performance of the past year.

0.4 Results

0.4.1 PE/PP Caps

The Freight Score is 3.33. This is due to a good input to output ratio and a good throughput rate. This is due to the overall good score the freight got on the expected throughput, toughness and weight. And the overall good score the freight got on freshness and sand.

0.4.2 Cups

The Freight Score is -1.06. This is due to a good input to output ratio and a bad throughput rate. This is due to the overall bad score the freight got on the expected throughput, toughness and weight. And the good score the freight got on freshness and sand.

0.4.3 PP Mono Shred

The Freight Score is -5.25. This is due to a bad input to output ratio and a good throughput rate. This is due to the overall the good score the freight got on the expected throughput, toughness and weight. And the low score the freight got on freshness and sand.

0.5 Discussion and Recommendation

1. **Production Line: Extruders:** The same plan can be made for the extruders. This will give them a good insight in the material that the company produces.
2. **Added Value:** In order to get a better insight in the added value, a market analysis can be performed.
3. **Time Series Analysis:** A Time Series Analysis can be made if the data is registered an collected differently. With the help of technical innovations, a continuous and automated time series analysis can be made.
4. **Quality:** In order to establish a quality standard, an analysis has to be made in order to compare freights and link them to the performance of the production line.
5. **Improvements Measurement Plan:** The slick production can't be linked to a resource input, due to technical issues. The vitens water is not being measured, due to technical issues.
6. **Sustainability Analysis** The measurement plan has to be extended in order to do a sustainability analysis. It has to include the extruder lines.
7. **Water System:** The company has a extended and complex water system. More search can be done in order to get a better insight in the consumption of the production lines.

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Preface

This research contains the bachelor's thesis "Data Gathering Method to Measure the Effects of a Resource Input on the Production Process" to complete my bachelor's program in Industrial Engineering and Management at the University of Twente.

I want to thank Jan-Bert Jonker and Marco Kers, my company supervisors, and the management of The Paauw for giving me this opportunity. I also would like to thank Richard Altemuller for helping me with this project. And I would like to thank the washing line operator Ashifou and George for supporting me with the execution of the measurement plan. And I would like thank Marko Kers, my father Mark Langenhof, my father Eric Rinsma, Leon Scholtens, Kevin Zieverink, Jeroen Oude Lenferink, Marcko Cherry, Nikki, Nick, Arnould, Roy Mekkelholt, Romano, Stef Kattenpoel and Stef Takkenberg, for their help.

Furthermore, I would like to thank my first supervisor at the University of Twente, Devrin Yazan, for his feedback and guidance on concept versions of this report.

Definitions

Table 1: Overview of used Definition in Project

Term	**Explanation**
HKW	Dutch for: Harde Kunststof Waslijn English for: Hard Plastic Washing line
FWL	Dutch for: Folie Waslijn English for: Foil Washing Line
Resource Input	This is the plastic waste that is being used as input in the production line.
KPI	Key Performance Indicators

Chapter 1

Introduction

1.1 Introduction to Rodepa

Rodepa is a recycling company which turns industrial plastic waste and consumers plastic waste into high-quality regranulate and regrind. They can wash the contaminated waste and turn it a product that can be extruded. Rodepa produceses 30.000 MT regranulate and 10.000 regrind every year. The company has 5 modern production lines that extrude waste into product and also 2 modern washing lines that clean the contaminated plastic waste and shred it.They also advise other companies on plastic recycling. In addition to their core business, they have a logistical branch, which provides transport to and from the customers or plant. My place within this organisation is a researcher that will be unraveling the black box: the production line.

1.2 Problem Context

Rodepa has 5 extruders lines and 2 washing lines. And every single line can be seen as a black box with an input, and a certain output and waste. And because there is a big variation of waste plastic, a saying they like to use is: “Waste can’t be made to order”, and each waste stream has an effect on the waste and output of a production line. One waste stream is more contaminated that the other waste stream, so it uses more water or filters have to be changed more frequently. And this is one of the many factors that can have an impact on the performance of the production line.

The black box is relatively unknown to them. They do have a lot of experience, so they can guess some effects of a waste stream on the process, but they can’t quantify them and substantiate them. Currently the margins are calculated by subtracting the cost price of a waste stream and the guessed consumption of additives from the selling price. The true margins can’t be calculated.

The challenge they proposed to me is that they want to unravel the washing lines blackbox. They want to have a more precise overview on the margins they make. Each stream has certain effects performance, wear and tear, output and waste. These effect can be measured, but they currently don’t know how. They want me to come up with a plan or a tool to

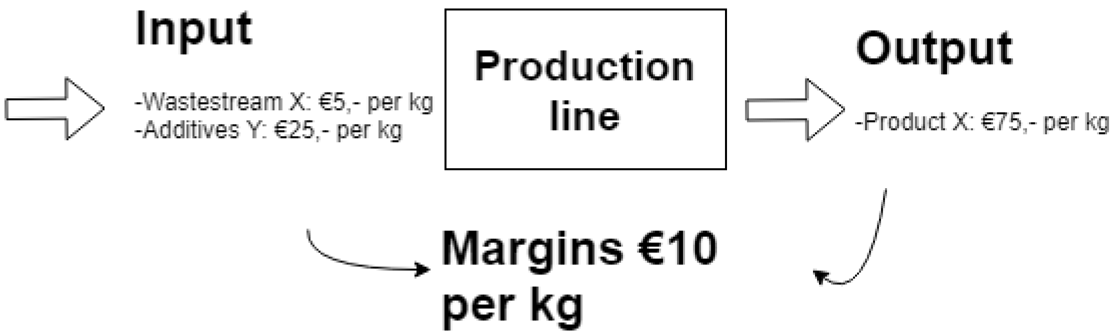

Figure 1.1: Graphical Description of Problem

give better insight in these effect and eventually the margins. So they can get an overview which waste streams they should buy and which they should avoid.

They want to know whether the margins they currently assume, are the true margins. In the example above there is a small illustration. The 10 euros profit margin per kg is what they currently assume and they want to know whether that 10 euro margin truly is the 10 euro margin or whether it is higher or lower.

1.3 Problem Cluster

A more elaborate explanation can be found in appendix B

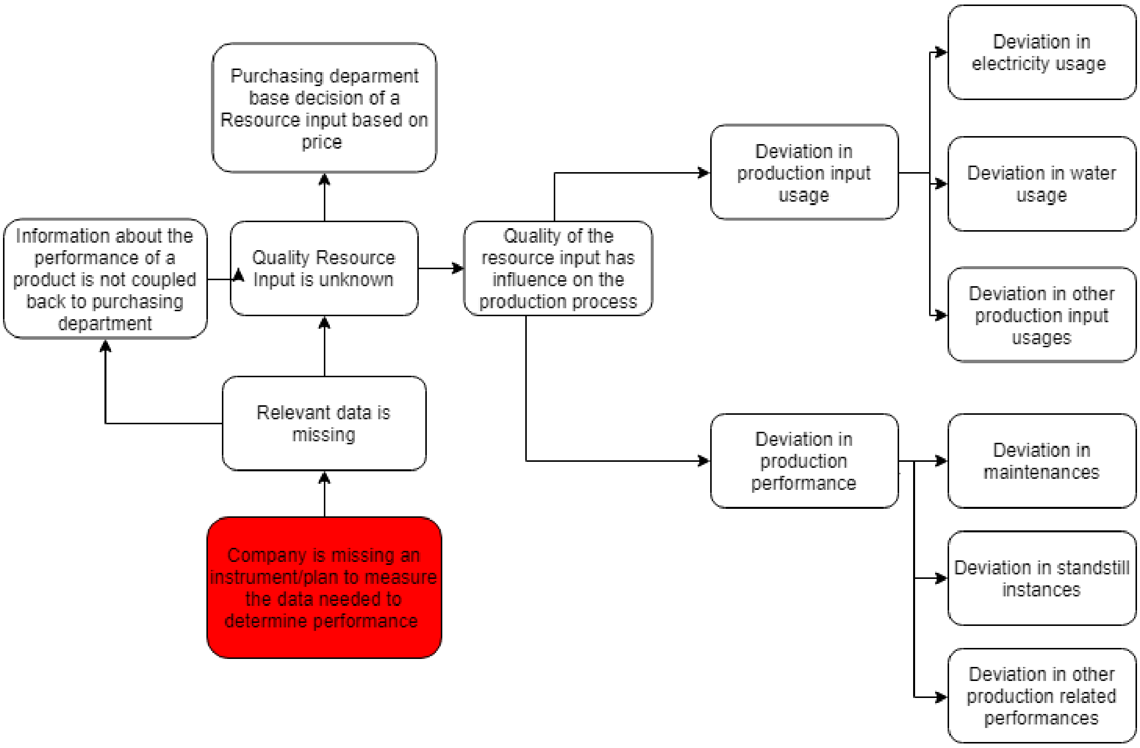

Figure 1.2: Graphical Overview of Problem Cluster

1.4 Core problem

My core problem is the following:
The company is missing an instrument/plan to measure the data needed to determine performance

1.4.1 Motivation:

The information related to the performance of a production line when considering to buy a certain waste stream is unknown to the organisation. They started with gathering more data on the performance of the production line, but only since a couple of month. And from interviews with production staff, production planners and lab staff, I can conclude that certain properties of a waste stream can have an impact on the performance of a product. The waste can contain a lot of sand, which has a big effect on the filters.
If Rodepa want to maximize their margins, they want to minimize unexpected maintenance, waste and electricity and maximize the flow, output and occupancy rate. These factors all depend on the input. They have a limited capacity on their lines and have to maximize that capacity, if they want to get the correct product on time to all their customers. This can only be done on basis of information. The company lacks methods and systems to gather and process this information.

1.5 Norm and Reality

1.5.1 Norm

The precise margins are known to the organisation, because they have a measurement plan/system. The effects of a certain resource input on the production line can be measured. All parameters needed that can explain the effect significantly are known and measured. With the amount of data that they have gathered with this system, they can predict with a certainty the effects of a resource stream based on a sample.
All the inputs and the outputs of a production line, according to the Black Box Design, are known to the company and can be quantified. They keep track of the total inputs and outputs relative to a resource input.
With this system they can estimate quite precisely the real production costs of a production run. For example the electricity consumption, the waste input and water input can be measured on the input side. The amount of silk, waste, the amount of maintenance-related operations and the amount of wear and tear can be measured on the waste side. And all of this can be traced back to the end product.
On the basis of this information, they can calculate the margins made on a freight. The information is coupled back to the purchasing department, in order to do a strategic measurement. The whole measurement plan can be statistically substantiated. It can be carried out within an workday and is cost-effective method. Or can be done real time via a monitoring system with sensors, such that a sample wise measurement is not necessary.
The information from the measurements is coupled back to the purchasing department. They can make better decisions on which waste streams to buy from which suppliers. Because they know from the taken measurements and documented data on the production line performance what the influence of a waste stream is on the production line. They can also keep track of the performance of the supplier and whether they still deliver the same quality of waste.

1.5.2 Reality

The precise margins are unknown to the organisation, because they don't have a measurement plan/system.
The organisation lacks the system or method to measure the effects of an resource input to a production lines. They can keep track of the electricity consumption, the waste production, water usage, slik production, maintenance over all the 7 production lines and not the individual ones.
They calculate the margins by subtracting the buying cost, packaging costs and estimated additive costs from the sales price. The energy cost and the other costs mentioned above are not taken into an account in the precise margins and are written off as overhead.
Most inputs and the outputs of a production line, according to the Black Box Design, are known to the company and can be quantified. They keep track of the total inputs and outputs not relative to a resource input. A precise description of their current KPI measurements

can be found in chapter 4.
The decision to buy a resource input is based on price and the material that is needed in their production process. They have criteria on which they can reject a load of resource input.
The performance of the production line is documented and they keep track of amount of end product form the production. This information is not linked to the resource input. It is known within the organisation, but not coupled back to the purchasing department. They do not keep couple this strategic information back to purchasing department.

1.6 Research Goals

This research has to give the company better insight in:
The company want better insight in the performance of a resource input on the production process. They want a plan to in order to better determine the performance of the suppliers from which they get the resource input. The quality of the resource input from a supplier varies, but this is not taken into an account when purchasing resource inputs. In the future they want to go towards strategic purchasing and they need data to start determining the performance of suppliers.
You need a system or plan to come up with the necessary parameters, in order to better calculate the true production costs and the production performance of a resource input on the production line. As mentioned earlier, waste can't be made to order and differs in quality per supplier and the properties of the product. The company can make an better estimation then in the amount of profit they make and possibly are going to make if they use a certain resource input.
Second off, the company has a lot of assumptions about relationships between variables, but they cannot substantiate them. With a new data gathering method they can start with building a database that can substantiate those assumptions.

1.7 Research Questions

The main question of this research is:

What is the production performance of a resource input during a production run?

Production performance in this case can be subdivided into 2 parts: KPIs related to the resource input and the true costs of the production batch.

1.7.1 Phase 1: the Production Line

1. What is the process type of the production line?

2. What does the production line look like?

    (a) What is the process flow with the different parts?

    (b) What are the inputs and outputs of the different parts?

    (c) What states can a production line be in?

First, getting a clear overview of the process will help to understand what a resource input does in the production process of the HKW and the FWL. This will also help with determining KPIs and parameters which are relevant to my research question. To answer question 1 and 2a we will use the theory from the book Operations Management Nigel Slack, because this gives clear handles on which aspect I should implement in my process description. Question 2b will be answered with a Black Box input output design to give a schematic overview of the process. Question 2c will be answered with the production equipment state model (Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach). These questions will be answered by conducting interviews on site and in a conference room with relevant production personnel and possibly with the machine supplier.

1.7.2 Phase 2: The Purchasing Process and the Flow through the Company

1. What are the international quality benchmarks on foils waste and on hard plastics waste?
   This will be done with a literature study. It can be found in the literature study 2.

2. How does the process flow of a Resource Input look like in the HKW and the FWL?

3. What are the quality requirements on which a decision within the process is made?

This process will be modeled according to the BPMN 2.0 (2011,OMG). This will be done , in consultation with my supervisors, with interviews of several people relevant to this process. For example the people responsible for the purchasing and for the truck load acceptance.

1.7.3 Phase 3: Collect information about KPIs

KPIs are crucial to monitor the performance of a resource input on the production process of the HKW and the FWL. This gives insight in the cost drivers of the batch and possibly even give insight in possible improvement in the production process. This also gives an insight in possible cost drivers which are useful when assessing cost of a production run.

1. What is KPIs/parameters are currently being measured?

2. What KPIs are relevant to the performance of a production line?

3. What data/parameters are needed to calculate these KPIs?

We have to look at the influence of a resource input on the production process, in order to determine the performance of a resource input. This can be done with Key Performance Indicator, KPIs in short. The company can grade the performance of a batch run on the basis of these KPIs and in the future predict the performance. Question 1 will be answered with a small BPMN (Business Process Model and Notation) scheme and an inventory of the current KPIs. Question 2 will be answered with looking at the theory in Operations Management and with an literature review on KPIs related to the production process. The data or parameters that are needed to calculate the KPIs will be derived from the answers of question 1 and 2 and used in phase 3.

1.7.4 Phase 4: Parameters relevant to the KPI

In the previous phase, we came up with a list of parameters that needed to be measured in order to calculate the KPIs. This phase can be divided into two parts:

1. Production related parameters: these are the parameters that are need to calculate the production process performance derived from phase 2.
2. Resource input related parameters: these are the parameters of the resource input that can have an influence on the performance of the production process or in this case can be called quality of the resource input. This can be divided further into 2 other categories:
   (a) Technical properties of the input resources: e.g. tensile strength, type of plastic, size of resource input, thickness of material.
   (b) Supplier related properties of the input resource: e.g. amount of contamination in a load, mixture of plastics.

How reliable and valid is the data? The research question are used to answer both part of this phase:

1. What parameters have an influence on the production process?
   As mentioned in the research goal, there are assumptions about relations between parameters that can't be substantiated. The data to do this is collected and also in phase 4 start with the visualisation of the data. In order to substantiate those assumptions. This is done in interviews with the production personnel, lab personnel and also with a plastic researcher.
2. What parameters are already measured?
   (a) How are these parameters measured?
   (b) How reliable and valid is the data?

3. How can we measure the missing parameters?
    (a) What equipment can be used to measure the parameters?
    (b) How reliable and valid is the data?

This is done by doing making an inventory of the current situation. For the production related parameters we look at current KPI's and for the resource input related parameters we look at for example MFI measurements.
In this phase there will also a an choice made between a sample based measurement system and a real time measurement system of the missing parameters. This last question is part of the solution phase 4: formulating alternative solution. And the decision between these solutions will be part of phase 5: Choosing the solution. This will be done by the management.

1.7.5 Phase 5: Scoring And Ranking

In this phase, we will come up with a method to give a score to a freight and rank the suppliers. On the following question will be given an answer:

1. What is the definition of quality for the company?
2. What scoring approach can be used with the gathered data and method to qualify a resource input?
3. What are the deviations in plastic waste, that are found throughout the year?

1.8 Threats to Validity

In this part we will discuss the threats that could affect my research. This will be done with the book of Cooper and Schindler
Validity is commonly referred as (Cooper and Schindler, 2014) [1]: the extent to which we measure in a test what we want to measure. Next to that validity can be sub-categorized as internal and external validity. External validity of the research results is the possibility to generalize over multiple persons, settings and times. In the company there are multiple lines that are in certain ways very similar to each other. The way and equipment I measure my parameters can be applied to multiple production lines without many or even any alterations. Next to that the descriptions of the production line can be very much the same.
We can specify internal validity further in 3 sub-categories. The first one is content validity of instrument in which it covers the research question. In order to find all relevant parameters, I will have multiple interviews with multiple stakeholder from multiple perspective. I will have an interview with production personnel, plastics researcher and lab staff to get all the different perspectives to answer my questions. This will be sufficient to to answer this research question.
The second form of internal validity is criterion validity. The term “criterion validity” in which

the outcome of a measurement device depend on multiple criterium variables. This will be discussed when it is relevant to the research, because it is very specific to the measurement device.
The third form of internal validity is concepts validity, in which we look at the extent in which a research represents the underlying concepts. The terms in which I describe the process and the input and output have to be clear. There can be a lot of confusion when we call a resource waste in the recycling industry and when we call waste waste. Plastic waste to a consumer means something different than to a plastics recycler.

1.9 Reliability

Reliability is defined as followed by Babbie: if a research we're reproduced, to what extent would it deliver the same results? My research is mainly focussed on gathering data and developing methods to gather data. The parameters that you want to gather will mainly be the same, because some are basic and widely used parameters and KPIs. But the way the data is being gathered may differ. This is depending on the amount of money that you want to invest in a measuring plan or system to gather these data. There is some subjectivity. During the interview I want to come up with parameters that can influence the production process. This can be done with from different perspectives as discussed earlier. Different perspectives come up with different parameters, so this could be an deviations if you were to reproduce the whole research.

1.10 Constraints

This research will be mainly focussing on the production line with the input and output. It will not focus on the whole supply chain of a company. The results of the measurements are contained to only this company and their specific production line.

Chapter 2

Production Process

This part will be used to describe both production processes, including all machines. There is also a description of all inputs and outputs of all the machines and one of the total production process. The theory used is from Bussiness Reseach Methods [1].

2.1 Description Production Process HKW and FWL

Both production lines have the same tasks. They both wash, extract waste and cut the input. The input is separated in contaminates, s.a. fine, big and heavy particles, and clean foil or regrind. In appendix A Description of the HKW and FLW - HKW you can find a more detailed description of the HKW. In Appendix A you can find a more detailed description of the FWL.

2.2 Manufacturing Process: Batch Processes

On the same production line they make different end product, because the input differs per batch. It can be that the end product is PP or HDPE.
But the production process does not differ per batch, the process tasks stay the same.This is due to the way the production line is set up. There are no options to make a bypass and skip a machine in the production line. Both lines have the function to wash and shred the resource input. So the transformation of the input is every batch the same.
The settings of the production process are different. For example, the screen sizes, the shredder settings and the additive settings differ. This depends on the resource input.
The process flow is continuous throughout a batch. And only stops when resource input has been processed and an other input has to be processed. The volume of the batch varies per freight, depending on the amount of freight of the same input that arrive.
In table 2.1 the difference between the different Manufacturing Processes can be seen.

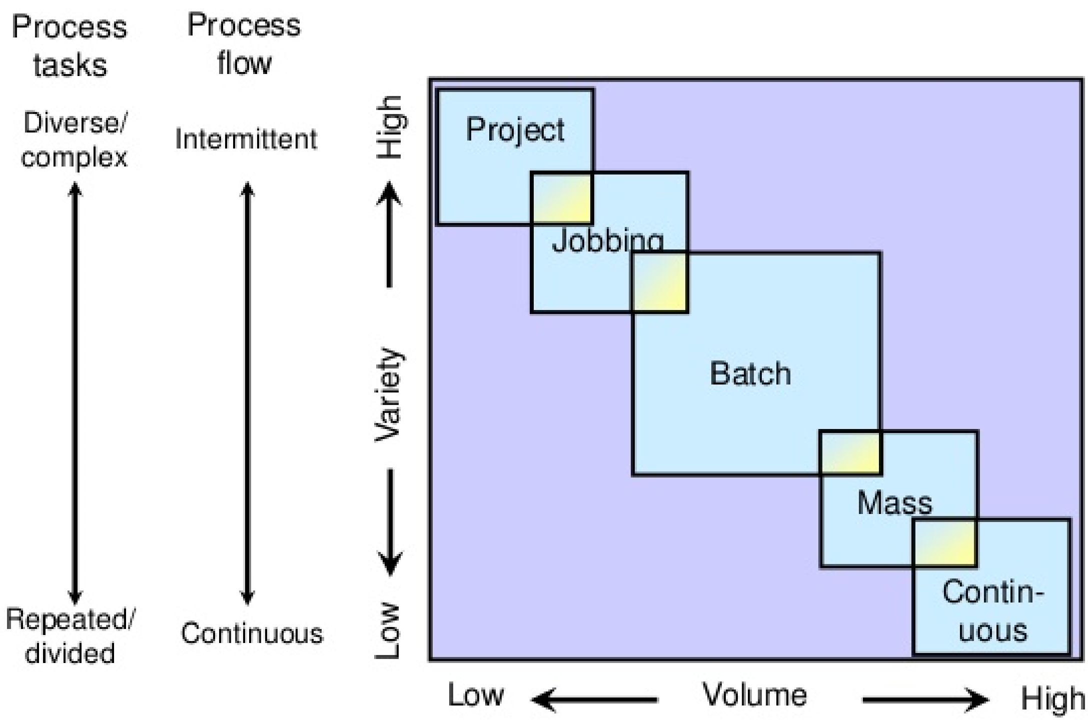

Figure 2.1: Overview: Different Types of Production Processes

2.3 Cell Layout

The input flows through the process in the order described in Appendix A: Scheme HKW and Scheme FWL. Every input is processed the same and the activities they use are the same for every input. After the input has been processed on the FWL or the HKW, they make the decision to process it further on the extruders. This process is described in the phase: A.

2.4 Long Arrangement

The stages in both the HKW and the FWL are sequential, so it is a production process in a long arrangement. The description of both lines can be seen in the Appendix A Scheme HKW. Every input has been processed by all the same machines.

2.5 State of Production Line

The states in which a production line can be, is done according to the electricity consumption of the shredder. This is done with the help of the study: [2].The process, although it is one system, can be seen as 2 consecutive systems: first the shredder and then the washing line. The shredder feeds into the bunker which regulated the flow into the washing process.

By looking at the electricity consumption of the shredder, the state of the shredder can be determined. This is also done further in the research, where I will be registering the start and end times in which the shredder has been in a certain state. According to this study there are 5 possible states which can be found in the table 2.1.

Table 2.1: Overview of Production Line States

State	Description in Paper	Description applied to my Research
Off	The process is not used and is not in use (unpowered)	The shredder is off and not using any electricity and is not producing any output
Busy	The process is working to produce product	The shredder is shredding the material to a certain size.
Starved	Missing input material so the equipment is paused.	There is no input material in the shredder that can be processed.
Blocked	Process output is full and the equipment is paused.	The bunker is full and reached a certain max, such that the conveyor belt feeding the shredder and the shredder itself stops
Down	The process has a fault or a breakdown	In the waste was a part which the shredder won't shred, such that the shredder breaks down.

2.6 Blackbox Description of Production Line

A short blackbox description of both washing line is made below, for the HKW 2.2 and for the FWL 2.3. It is full with all the input needed to get the necessary output, including with the waste streams. In this case waste is also considered waste for the company because they do not turn it into a usable product.

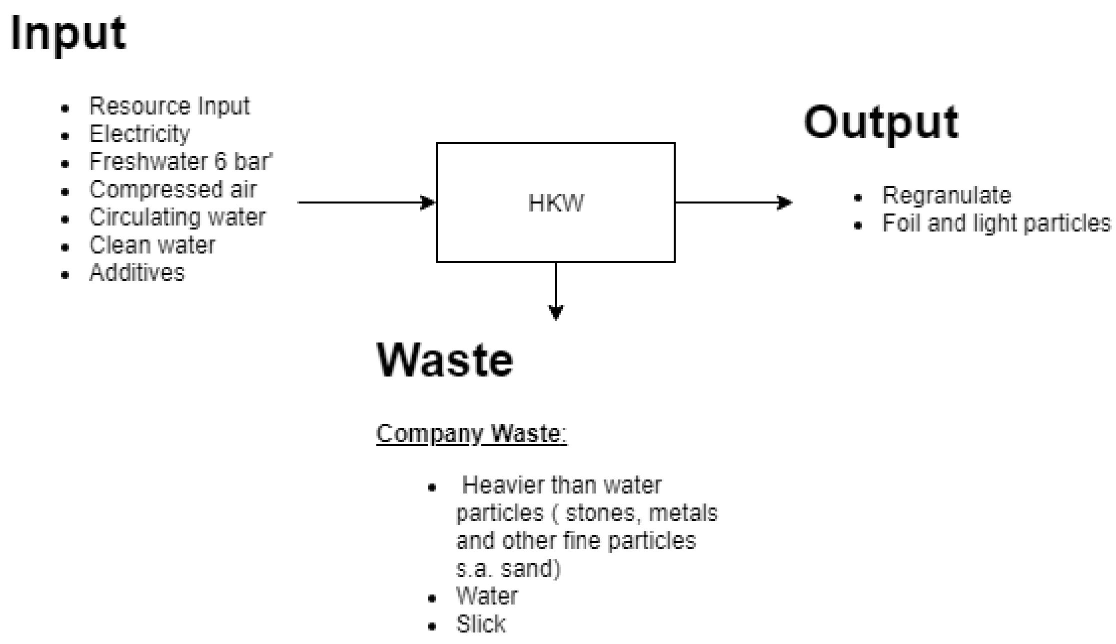

Figure 2.2: Blackbox Description of HKW

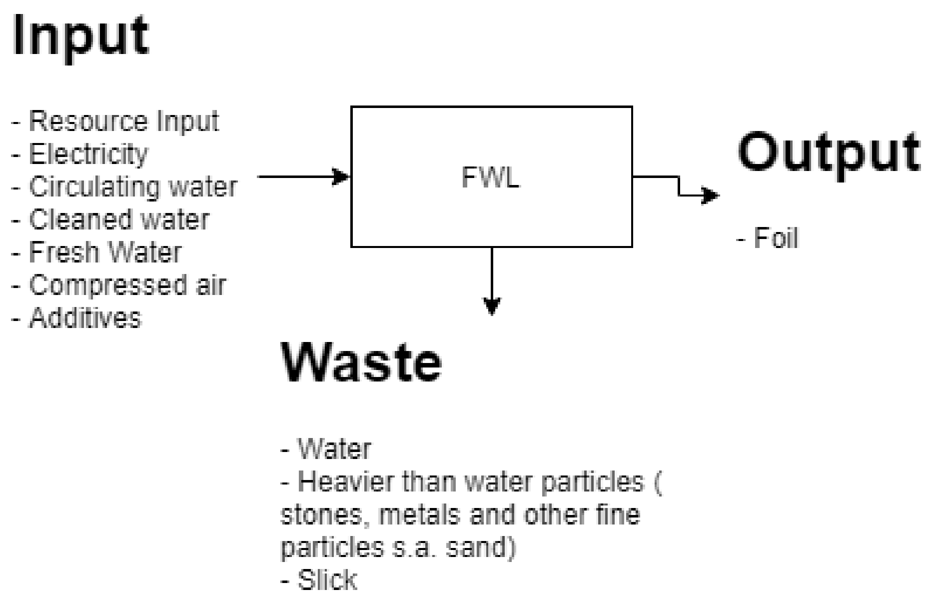

Figure 2.3: Blackbox Description of FWL

1. **Resource Input**

This is the plastic “waste” that will be washed, shredded and separated from actual waste.

2. **Electricity**
All machines in the production line use electricity in order to operate.

3. **Cleaned water**
This is water that comes from a well in the company. It is groundwater, which is pumped to the surface and then cleaned inside the water cleaning unit of the company.

4. **Fresh water**
This is water which could be regarded as tap water. It comes straight from the water supply.

5. **Circulating Water**
This is water that has been circulating in the system, and is cleaned water that we regard as waste in the black box description. It has been used before in the production process as an out of one of the machines in the HKW, FWL or one of the extruders and will be cleaned and then re-used as an input in one of the machines. It is a combination of previously used Fresh water, Source water or Circulating water.

6. **Compressed Air**
Certain machine in the production line use pneumatic valves and other pneumatic operated parts. This won’t be considered in the measurement plan, because it is relevant for the costs calculating.

7. **Additives**
There are 2 or 3 additives that are used in the FWL and HKW:
   (a) A binding liquid that assures that the contamination binds together.
   (b) Regulated the pH of the water.
   (c) HKW only: makes sure that there is no foam production.

2.7 Full Production Line Description

The specification of the machines of both the HKW and the FWL are done according to this scheme. The total production line can be found in Appendix A Scheme HKW and Scheme FWL. The description of the machine in the production line is done according to this format:
Name

1. Code in scheme (and on the production monitor.)
2. Short description of task of the machines

Blackbox Description

1. Input: Output of the previous machine in line.
2. Output: can be both end product of the machine and the waste

2.7.1 HKW

Here is a short description of the workings of the HKW.

Pre-Process

The hard plastic waste, or input, arrives in compressed bales or in bulk, delivered in the bunker by the forklift operator or directly from the truck. The bunker is used as a buffer before it is processed on the production line. Then a forklift operator places the bales or bulk directly in the shredder and it starts the process.

Production Process Stages

1. The input goes into the shredder (No Code), where is it shredded until a certain millimeter, such that it can pass through the sieve.
2. Then the input is transported to the Separation Tanks (1.50). Based on the float-sink principle, the plastics are separated from the heavy materials, such as stones, glass etc.
3. The input is transported to the Friction Separator (2.40). Where a screw separates the water and fine particles from the plastics.
4. Then it goes in a grinding mill, which has the same function as the shredder.
5. Again it goes through a Friction Separator (2.60).
6. Then is goes to a big Separation Tank (3.50). Which is a bigger Separation Tank, but has the same workings as the smaller one.
7. Then it goes to the Dewatering Screw (3.60). It transports the input to the Dryer and helps with the dewatering of it.
8. Then it goes to the Mechanical Dryer (4.50). Where the material is accelerated and separated from the water.
9. After that it is being sucked to the Rotating Feeding Device (5.40). It is used to separate dusts and soft shavings and fibres from the regrind.
10. Then it is being transported to the Air Separator (5.50). Here are the big and small or heavy and light particles separated from each other.
11. In the previous step, the foils and the hard plastics are separated from each other and sucked into 2 separate big bags.

2.7.2 FWL

Here is a short description of the workings of the HKW. The machines can be linked back with their code (number 1 in D) to a machine in the schematic drawing form Appendix A Scheme FWL. Pre-Process
The foil waste, or input, arrives in compressed bales, delivered in the bunker by the forklift operator or directly from the truck. The bunker is used as a buffer before it is processed on the production line. Then a crane operator places the bales on a conveyor belt and it starts the process.

Production Process Stages

1. The input comes of the conveyor belt and goes into the granulator (1.60) which cuts the foil in smaller pieces.
2. The foil is transported towards the prewashing vat (2.50) where the foil is separated from the crude contaminates such as stones. This is done according to the float-sink principle, where the heavy particles sink and the light particles float.
3. The foil goes to a Friction Separator (3.40), which separates the foil from the water and the fines particles. Then it is cut into even smaller bits by the cutter mill.
4. The foil goes to another Friction Separator (3.60).
5. The foil goes to the a hydrocyclone (4.40). This machines is similar to the prewashing vat, because it works according to the float-sink principle. The difference is that the water containing foils is pumped in the hydrocyclone. This creates a centrifugal force which has a better separation effect of the heavy and light particles.
6. Then is goes to another Friction Separator (4.50).
7. The foil goes to the Dryer (5.50). This is a mechanical dryer that centrifuges the foil dry and then blows it dry.
8. Then it goes to a second Dryer (6.50).
9. The end station of the foil it the Silo HRS (7.50), where it can be put into big bags or directly transported to an extruder.

Chapter 3

Quality Checks

In this phase there will be an overview of the different quality checks that are available for the plastic waste internationally and the internal quality checks at Rodepa Plastics.

3.1 Plastic Waste as Resource

Plastic waste is not your usual resource. If the demand in wood or oil increases, then the production of wood and oil adjust to meet that demand. If the market demands more recycled plastics, then it is harder to meet that demand. Because you can't increase the production of waste. Waste is a by-product of a production process or a by-product of the consumption of goods, and not like an oil well were you increase the production to meet demand.
Also does it not come from one source and a mixture of different sources. Which may include a single source, such as factory scrap or demolition scrap or a mixture of sources, like post consumer waste. Wood for example comes often comes from one source.
There can also be a lot of deviation in the content of the resource from different sources. It can differ from a single polymer type to a mixture of polymer types. And the extent in which a mixture occurs can also differ from freight to freight.

Within the company there is a saying: "Plastic Waste is not made to order". No freight are identical. There are so many deviations that can occur in a freight which is purchased under the same name. These are deviations, that can occur for example during the production process of the waste supplier. For example, there can be a mixture of black film in a freight of white LDPE end product. This can be the case, because the supplier has a problem within the production process. And in order to make a white LDPE end product, you need a pure white LDPE input.

The content and the form in which the waste is delivered can vary between freights, so it is necessary to characterise the plastic waste in a certain way, such that the quality can be assessed. The standards, international and at the company itself, are discussed in the following part.

3.2 International Quality Benchmark

3.2.1 Quality Benchmarks For Plastic Waste

According to the technical report of the European Commission: "End-of-Waste Criteria for waste plastic for conversion" (2014) [3], there is a lot of freedom in the formulation of the quality requirements between the seller and the purchaser. This depends on 2 things, the applications for which the purchaser can use the plastic waste and which impurities from the plastic waste can be removed. So the quality standards and agreements differ from recycler to recycler. Which is also something that can be noticed at Rodepa.
For example, the recycler has a waste processing line can effectively remove paper labeling on the film, which can add a lot of value to the freight.
That there exists a lot of freedom in the quality standards, can be seen in the different quality standards used by countries throughout the EU and outside the EU. For example, Germany has "Der Grüne Punkt", the US has the ISRI the standards- and code system and the UK has the PAS-103 specification. They have a lot of similarities but also some differences.

3.2.2 Quality Benchmark from Plastics Recyclers Europe

Rodepa is part of the Plastic Recyclers Europe. This is an organisation that promotes and protects the interest of plastic recyclers. They do not have quality standards for plastic waste or the resource input, but they do have guidelines [4] on how to characterise the waste bales input. And with these guidelines recyclers can make their own quality benchmarks or standards. You can find the Film bales characterisation in Appendix H.3 Incoming Freight Report. And you can find the bales characterisation for HDPE bales in Plastic Recyclers Europe: Bales Characterization Guidelines: HDPE Bales H.2. Both are similar to the ones described in Appendix H "Der Grüne Punkt"- 324 and they have similarities with the quality standards used at Rodepa.

3.2.3 Duales System Deutschland Quality Standard: Der Grüne Punkt

A portion of the incoming freight for the HKW is according to the quality standard of Der Grüne Punkt (DGP). This is a certificate that recycling companies can use to certificate waste, which has certain characteristics.
Packaging companies pay a fee for the use of the brand and the participation in DGP. This depends on the amount of packaging and type of packaging material used in their products. For example, Unilever pay a fixed fee for their 15 grams of a package, which they use to pack their Dove Shampoo. And they sell each 1 millions bottle every year. So they have to contribute the fee times 1 million for their shampoo bottle.
The quality of plastic waste waste or the resource input is determined according to their standards: "Der Grüne Punkt", which can be found below. There are many different types of waste that are characterised according to their standards.

Der Grüne Punkt

The resource input that is being used as input is according to this norm. There are multiple quality standards that are under the certification of DGP. The most commonly used resource input at Rodepa is the quality 324. There are more plastic waste quality standards according to “Der Grüne Punkt”, but they won’t be discussed.
Appendix H “Der Grüne Punkt” - 324 - PP you can find an overview of the quality requirements of this freight. In theory the amount of impurities are 6% at max. So when a 324 resource input is processed at Rodepa, there should be no more than 6% loss of the amount of input material. But the impurities are in practice much high and this number is not realistic. Depending on the supplier, they deviate around the 20% and 30%. Below you find 2 main reasons for this number.

Waste Market

According to the study “End-of-waste criteria for waste plastic for conversion” this is due to differences in specification that the EU and other continents like Asia have. The specification for plastic waste are lower and less for the Asian market, than the specification in the EU. In order to meet the higher specifications for new products in the EU, the recyclers and the collectors have more responsibility to ensure that the specifications are met. So they have a lot more customers to which they can eventually sell the plastic waste, without having to put a lot of effort in to reach a required quality specification.

Waste Management Companies

In the Netherlands, household plastic waste is separately collected and sorted. Waste management companies are payed per ton of waste they collect. From this price, they have to organise the collecting, sorting and redistributing of waste. The waste management companies have received their fee for collecting and sorting the waste. An effective way for them to increase their revenue is to process plastic waste faster. The more profit they make and the higher their return on investment.
To achieve this, is by turning up the processing rate of the sorting facility. This way they produce more output, which they can sell. The downside to this is that an increased processing sorting rate, has a negative effect on the sorting accuracy. This has a negative effect on the quality of the end product, which is used as a resource input for the washing line. Customers of the waste management companies, such as Rodepa, have an influence on the quality of the sorted waste. This depends on the state of the market. If the customer have more choice in their supplier, because there is more available, then they can demand more from their supplier.
Waste management want to sell their product, so they will adjust the quality of their product to meet the demands of the customers. They achieve this by decreasing the production sorting rate, thus increasing the sorting accuracy. Depending on the state of the market, quality of the resource input deviates.

3.3 Processed Plastic Waste Quality Standards

The following standards and certifications are used for plastic regrind and granulated. Regrind and granulated are the products that are created after the washing process and/or extrusion process.

3.3.1 REACH Certification

The REACH certification, short for Registration, Evaluation, Authorisation, and Restriction of Chemicals, is used to help companies by providing procedures for collecting and assessing information on the properties of hazardous substances. Under substances you find glass, rubber and other substances, but most importantly for my research is plastics.
All new or imported substances have to be registered according to the REACH standards. They have to me meet EU regulations. This process is controlled by ECHA (European Chemical Agency), which evaluates individual registrations for their compliance. They assess possible hazardous substances by the risk they could pose to the health of the environment. Because Plastics is also a substance, it also has to apply to the REACH obligations.

End of Waste

The EU has a Waste Framework Directive [3] which regulates the so-called "End-Of-Waste". Plastic waste ceases being waste, when the End-Of-Waste requirements are met (Appendix Waste Frame Directive) H.1. If a companies can process waste into a useful product, as is the case with certain types of plastic waste, it can be called a substance or resource. The plastic waste, that is considered waste according to the End-Of-Waste directive, can be called a resource in the future depending on the development of the recycling industry. As long as they can make a substance from it. The directive can be found in appendix H.1.
If the plastic waste is passed by the Waste Framework Directive [5], then it is covered by the REACH. The recyclers, or according to ECHA's Guidance on Waste and Recovered Substances called recovery operator, are able to benefit from this exemption under Article 2(7)(d) of REACH. They do not have to register their substance again, but they have to provide a SDS (Safety Data Sheet) with the substance that they produce.

Basis of Recycling with REACH

Recyclers can assume, according to this article [5], that the recovered plastic waste has been registered before in accordance to REACH. We can make this assumption, because all plastic waste recycled in Europe, comes from Europe or is imported. And all these plastics have a REACH registration, otherwise it would not have been in Europe.
A second assumption we can make is that all the plastic waste is short cyclic, so it from the time it has been released and the time that it is collected by a waste collector is less than a year. All substances that have been released in the past year are in according with REACH, so we can assume that the substances in plastic waste are also in accordance with REACH.

In practice, it could be that a plastic crate of 30 years old contains a SVHC. At the time this article was released, it was in accordance with REACH, but ECHA later found out that a substances in the article is considered a SVHC and thus loses it REACH certification.
The relevance to the quality is that every substance that has been approved and has an REACH certification, such that the contamination is contained within predetermined boundaries. This means that the amount of contamination, or according to REACH: Substances of Very High Concern (SVHC), are within the limits, such that is can be harmful for the population of Europe.

3.3.2 EN ISO 15347

This is a general standard for plastic waste, after it has been collected and sorted: the EN ISO 15347 "Plastics - Recycled Plastic - Characterisation of plastic wastes laying out those properties for which the supplier of the waste shall make information available to the purchaser' [6].
Throughout the years, various countries developed different standards such that plastic waste could be categorised accordingly. ISO takes the best of all the different standards that have been developed throughout the years and tries to make a general formulation for a batch of waste plastic.
In Appendix I Required and Optional Characteristics of plastic waste, you can find the different criteria on which you can measure the quality and how you can measure it, according to this norm. Certain criteria are required and others are optional. These depend on the agreements between the supplier and the recycler. They also provide an additional ISO norm with which you can measure that parameter.

3.3.3 Transparent Foil Benchmark 98/2 - 95/5 - 90/10 - 80/20 - 50/50

For plastic foil there are 4, under recyclers known, benchmarks for transparent LDPE-film. A 98/2 quality standards, is characterized as a pure film with at least 98% of transparent LDPE-films and a maximum of 2% colored LDPE-films. The other known standards can be found in the table 3.1. And it is delivered in compressed, dry bales.

Table 3.1: Overview of Quality Standards

Quality Standards	Transparent LDPE-Film	Coloured LDPE-Film
98/2	>98%	<2%
95/5	>95%	<5%
90/10	>90%	<10%
80/20	>80%	<20%
50/50	>50%	<50%

There are small impurities allowed for this quality and all the other qualities. In the table 3.2 you find the impurities with their tolerances used for all quality standards.

Table 3.2: Overview of Impurities Quality Standards

Impurity	**Tolerance**
HDPE Films	<5.0%
PP-Films	<0.1%
Wood	<0.1%
Paper, Including plasticized paper	<0.1%
Metal	<0.1%
Glass	<0.1%
Other contaminants, such as organic components, sand and stones	0.0%

This is often due to the fact that the bales are still waste. Not every bale can be checked in order to measure whether it hold to these standards. There are also no objective methods to measure these impurities and there are practical difficulties to measure this, as will be mentioned later in this chapter.

There is a well known fact at the company, where this research is conducted, that every waste bale is unique and will never come back. So every bale has a different percentage of, for example, colored film or other impurities throughout a freight.

Industry Known Standard: Important Side Note

This is a well known standard in the recycling industry. This gives an indication about the quality of the bale, but it is based on a subjective test. And in order to drive up profit on a plastic bale, a supplier can grade the plastic bale for more personal gain. Thus a supplier can grade the bale as a 98/2, while in fact it is a 95/5 or worse. This standard can't be used objectively, because there is a financial incentive to grade it differently.

Second off, it does not give a good representation of what a client, for example Rodepa, is grading the plastic bale on. The main thing they judge on are transparent LDPE-Film and coloured LDPE-Film. And do not regard the following items:

- The freshness of the material: so the appearance and the visible contamination.
- The content of non-PEs in the plastic bale, for example PP foil.
- The amount of print on the foil itself, for example a shopping bag.
- The amount of stickers on the bales, for example registration stickers.
- The moisture content, which has an major effect on the weight.
- The thickness of the foil, which gives an indication how much contamination it potentially contains.

3.4 Process Flow

The Quality Check Process Flow can be found in D.2 Appendix Process Flow.

3.5 Rodepa Quality Management

Common

Within Rodepa, resource inputs are specifically bought for an end product by the purchasing department. The path throughout the production process is determined upfront for a resource input. So for example, the resource inputs are specific bought to go over the HKW or the FWL, which then goes to the extruder or straight to the customer. The end product can be both regranulate or regrind depending on the end product. Whether the resource input has, upon arrive, the specification that is needed to create an end-product, is still uncertain. This is not about the way that a waste stream is linked to an end product for a customer.
During the process there are quality checks and on the basis of these checks, a decision is made whether it meets the standards to process it further in order to meet the quality standards. See Flowscheme Appendix D.2 Flowscheme Quality Check for the path of a resource input.

Scope

The scope of the BPMN-scheme is to follow the path of the resource inputs, that are processed on the HKW and the FWL, throughout the company. The focus lies on the HKW and the FWL, but we will also take the extrusion process.

3.5.1 Quality Check 1 for HKW, FWL & Extruders

This check is meant to establish a first impression of the supplier and the quality of the resource input. This control is for both the FWL, the HKW and extruders.
The purchaser from Rodepa goes to supplier. He gets an insight in the come about of the resource input. Then he can assess the quality and possible deviations that could come about during the delivery of the resource input.
The purchaser or supplier makes pictures of the resource input, such that he can assess the freight. He also does some subjective testing depending on the resource. The pictures are also meant as a control measurement, that when the freight arrives at Rodepa is the freight that he bought at the supplier. This is done for both regrind and plastic waste.
If the resource input is meant for the HKW or the FWL, then the subjective tests of the purchasers office. There are no tests for plastic waste, other than subjective tests via pictures, that can be done on the freight.
Next, the samples of a waste stream or resource input from a supplier are being delivered to the lab of Rodepa. If the resource is meant for the extruders, then the lab decides which of the following test have to be executed, based on a first optical impression and experience. This can be the case with regrind.

The freight for the HKW are assessed according to the Quality Checks 1 that can be found in the appendix HKW Quality Checks D. The freight for the FWL are assessed according to the Quality Checks 1 that can be found in the appendix D FWL Quality Checks incoming.

If the sample meets the standards that are set for a resource input, then the decision is made to regularly purchase waste from them. These standards depend on the end product in mind and the quality of the resource input.

Objective and Subjective Tests for Extruders

The subjective test are judge with an OK (good) or a NOK (not good). The objective test are judged with a value corresponding to the measurement unit. For example, the density of a product is measured in mg/cm2.
The test for the FWL depend on the type of plastic. There are 4 types of foil that are being processed on the FWL: Ziegel Foil, Shrink Wrap, Bont Foil, Natural Foil.

3.5.2 Quality Check 2 for both HKW and FWL

Not relevant to this research, because it does not contain any quality related measures. But relevant in the flow of the resource input in the process. The trucks has arrived at the company and the truck driver reports to the reception. The following are checked:

1. Is the order number present and correct?
2. Is the truck freight planned to arrive?
3. Are all documents complete and correct?

If the following conditions are met, then the truck driver can proceed to the unloading area.

3.5.3 Quality Check 3.1 for the HKW and FWL

This check is the first real quality checks where it enters the company. It is performed by the forklift operator, when the truck arrives at the unloading bay. In the following part the quality of the freight is established further. Based on these decision a freight will continue to the HKW or the FWL.

FWL

The freights, destined for the FWL, are assessed according to the Quality Checks 3. The test that are used to assess the freight can be found in Appendix Quality Check FWL D. The decision that is made according to these test can be found in the same table. If the freight is within the quality standards, than it is being accepted and processed. All the freight of the FWL are delivered in compressed bales.

Figure 3.1: Plastic Waste Bale, that will be processed by the HKW

Assessing Freight

The difficult part with assessing a freight, is that you can not look into the bale itself. It is not possible to properly and effectively assess the freight via sampling.
The bales can look perfect on the outside, without any big contaminations, but on the inside have huge contamination. And every bale is different and unique. So the forklift operator would have to rip up the individual bales and assess them individually. Sampling can't be done effectively with foil bales.

HKW

The freights, destined for the FWL, are assessed according to the Quality Checks 3. The test that are used to assess the freight can be found in Appendix Quality Check HKW D . The decision that is made according to these test can be found in same table . If the freight is within the quality standards, than it is being accepted and processed.
A portion of the freights are delivered in bulk and a portion are delivered in bales.

Assessing Freight

The freights for the HKW are more transparent. The freight often comes in walking floor trailers, which are meant for bulk transport. The way a walking floor is being unloaded gives a good look inside the whole content of the freights. Contaminants can be optically checked and be spotted easily. The freight can also be delivered in bales, which make it harder to assess the quality, but it is still easier to check a bale.
If the forklift operator is unsure about the quality of the freight or about a type of contamination in the freight, then he calls in the help of the production manager or the lab.
The number of the test corresponds to a decision that is made about the freight. If the freight does not meet these quality standards than the freight is refused and a financial compensation is negotiated. Depending on the outcome of the negotiations, the freight is returned or

regarded as company waste and processed by another company via the De Paauw Recycling or an external company.

3.5.4 Quality Check 3.2 for FWL and HKW

After the forklift operator has approved the freight, it proceeds to the bunker or to the storage area. This is depending on the production planning.
The quality check is performed by the production manager of the Washing Lines. He is responsible for both the HKW and the FWL. And does the final quality check before they are processed. The checks that are performed are mostly optical and similar to those performed by the forklift operators. The checks can be found in Appendix HKW D Quality Checks and FWL Quality Checks D. Because the load in the bunker is more transparent, he can better evaluate these loads. This is especially true for the unloading of a walking floor.

Refused Freights
Whether a freight is refused or not, depends very much on the agreements the supplier and Rodepa have made upfront about the freight. So extent of the freights shortcomings are dependent on the agreements.
If there are small shortcomings, then the freight is sent retour or processed nonetheless. A financial compensation is negotiated, because you cannot reach a predetermined quality.
If there are big short comings, then the freight is send retour or, in accordance with the supplier, it is processed elsewhere. This means that the contamination is so severe that is would disturb the process.

Figure 3.2: Plastic Waste Bale, that will be processed by the FWL

3.5.5 Quality Check 4 for the HKW

These checks are performed, after it has been processed on the HKW and before it goes over the extruder or to the customer. This is where the product of the HKW and the product of the FWL differ from each other. The output of the HKW can be sold as an end product, while the output of the FWL is processed on the extruder before it is sold.
So in the Flow Scheme you can find Quality Check 4, but this check is skipped for the FWL due to technical difficulties.
The checks that are performed are similar to those in Quality Check 5.

3.5.6 Quality Check 5 for the HKW and FWL: End Product

After the product has been processed on the extruder, a quality check is performed on the output. Depending on the specifications needed for a certain quality of output of the washing line, which depends on the specification needed for the end product of a customer, an output will pass quality check 4. The tests that are used, are based on the experience of the lab with a resource input and based on the wishes of a customer. These are documented by the lab.

Chapter 4

Key Performance Indicator

In this part of the research we will discuss the KPIs used at Rodepa to monitor their process. And we will also discuss KPIs that can be used for the processing industry. The definition of KPI is Key Performance Indicator.

4.1 Data Registration

The data is currently being registered per shift by the employee responsible for storing the pallets and the team leader. Both the washing lines have separate reports in which they register production related data. The use of these sheets are to monitor the shift and not to monitor the resource.

4.1.1 Registration FWL

At the beginning of the shift they register the Date, the Shift they are in, Water level, Shredder Hours. They also register the name of the operator responsible for the document including a signature, and the signature of the operator responsible for the document previous to their shift. This is

The output is not being registered, so there is no data available on the amount of foil produced. The end product of the FWL goes straight to extruder, where it will be further processed. The registration of the data relevant for this research is listed below in table 4.1.

Table 4.1: Data Registration FWL

Data: FWL	Registration Unit	Precision
Date	Day-Month-Year	Not Applicable
Shift	Week: Morning - Noon - Night Weekend: Morning - Night	Not Applicable
Material Description: the material that is being processed on the line.	Trub Natur A-B / Natural-K/ Bont / Grey / Other	Not Applicable
Bale Number	RDP / DPPR XXXX	Not Applicable
Water Level: The amount of water from the well that is used during the shift.	Beginning: XXXX,x M3? End: XXXX,x M3?	During a transition of a shift, the production line is often still in a busy state. So it is still using resource, among them water. So the water usage is dependent on the time they register the water levels. The data is precise to one decimal number.
Beginning Shift	Hour:Minute	Not Applicable
Shredder Hours	Hour	The shredder does not round the amount of hours in use of. In theory a shredder could have turned for 5.9999999 hours and then the meter would still give 5. The shredder hours are also dependent on the time they register it, the same as with the registration of the water levels.

Registration HKW

The registration happens on the same way as described in the **3.1.1 Registration FWL**. The relevant data can be found in table 4.2.
In comparison to the FWL, the output of the HKW is being registered. The foil of the FWL is blown straight into a Silo that will process it in the extruder.

Table 4.2: Data Registration HKW

Data: HKW	**Registration Unit**	**Precision**
Date	Day-Month-Year	Not Applicable
Shift	Week: Morning - Noon - Night Weekend: Morning - Night	Not Applicable
Material Description: the material that is being processed on the line.	Sticker places on all the bales of the freight during the unloading process.	Not Applicable
Water Level: The amount of water from the well that is used during the shift.	Beginning: XXM3? End: XXX M3?	During a transition of a shift, the production line is often still in a busy state. So it is still using resource, among them water. So the water usage is dependent on the time they register the water levels.
Beginning Shift	Hour:Minute	Not Applicable
Shredder Hours	Hour	The shredder does not round the amount of hours in use of. In theory a shredder could have turned for 5.9999999 hours and then the meter would still give 5. The shredder hours are also dependent on the time they register it, the same as with the registration of the water levels.
Solid Waste Weight	XXXX KG	Precise till zero decimals
Solid Waste Bin Size	Bins with a weight of 430 or 630 Kg	Precise till zero decimals
Foil Separator Big Bags	XXX KG	Precise till zero decimals
Output: Time	Hour:Minute	Depending on the persons registering the output, the precision can be 1/5/10 minutes.
Output : Material Description	Same as material description above	Not Applicable
Output: Kg End product in 1 Big Bags	XXX kg	Precise till zero decimals

4.2 Current KPIs

After someone has collected the data registration papers, they are being processed and put in an Excel Data Registration Sheet.

Available KPIs: KPIs of both the HKW and FWL: These are not per batch, but are taken over the whole week. The registration is done per shift. A brief overview can be found in the table 4.3. All KPIs used are shown in numbers, except for the total output of all extruders

and washing lines in one week over a whole year are shown in a chart.
A more elaborate list can be found in the Appendix Inventory Current KPIs E.

Table 4.3: KPIs that are currently used by Rodepa

KPI according to Theoretical Framework	Parameters
rocess KPIs	
Quality	Waste (per hour), Foil Waste, Slick/Sand Waste, Water Usage (per hour), End Product, Recovery Percentage
KPIs Measurement Elements	
Time	Shredder Hours
Quantity	Water, Waste, Foil Waste, Slick/Sand, End Product
Equipment KPIs	Shredder Usage
Disclaimer Sand/Slick	The HKW and the FWL both produce sand and slib waste. The sand and slib from the HKW goes over the water filtration system of the FWL before it is deployed in a waste bin.

4.3 Literature Review: Available KPIs

Rodepa is a production company, which turns a waste stream into a resource. The scope will be on both the HKW and the FWL. And the company wants to know what a production batch actually costs to run on those lines. And this will be done with a measuring plan in which want to take into account not only financial aspects of the production process, but also the performance aspects. This can help with explaining why the production run of almost identical material deviates in yield and costs.

4.3.1 Literature Review

Which KPIs will help me to indicate the performance of the production lines in a process industry. And which, on it's own, will help me to determine the performance of a production run. To answer this question we will perform a theoretical literature review. The literature review can be found in Appendix Literature ReviewF, with the correct steps and explanations. During the literature review the article about "Key Performance Indicators for the Manufacturing Operations Management in the process industry" [**?**] was used, in which they propose a framework for organizing the KPIs. Both the HKW and the FWL are a continuous process. This requires slightly different KPIs than the KPIs standards from the ISO 22400 [7], because those are more focused towards the discrete industry. In the discrete industry you produce distinct items, such as toys, in comparison to the process industry, where the product is produced per batch. It came up during the literature review and will be used during this research.

4.3.2 Maintenance KPIs

Additions to these KPIs are maintenance KPIs. The production line has periodic maintenance elements, such as filter change and cutter blade change, that are changed after or during a batch run. KPIs related to maintenance will come from the article: "A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems". [8]

4.4 Theorectival Perspective

The first step is to establish a point-of-view or a theoretical perspective in order to categorize the KPIs, that will be used to describe the performance of the production line. The framework can be found in Appendix Literature Review F with KPIs that are categorised with this framework in mind. It also contains KPIs and measurement elements from other studies. There are 2 perspectives in which KPIs are defined, namely Equipment KPIs and Process KPIs. And these perspectives can be categorized further, which will be explained further in the report. The measurement elements are used for the calculating of the KPIs. In the table 4.4 below you can find the categorisation that is subtracted from the literature.

Table 4.4: KPIs according to the Theoretical Perspective

Process KPIs			**Measurement Elements**		**Equipment KPIs**	**Addition**
Production	Quality	Energy	Time	Quantity	Allocation/Utilisation	Maintenance

KPI Scope

The scope of this research will only be on the HKW and FWL production lines, so we won't be considering KPIs related to logistics or personnel.

4.4.1 Process KPIs

These KPI are about the total performance of the production line. These KPIs are most relevant for my research, because my goal is to calculate the performance of the total production line. The process KPIs can be further specified into 3 further categories:

- **Production**

  Production KPIs are related to performance of the production line, in order to get a good overview of the influences a stream has on the production process. This way we can rank a stream. There is a lot of different material that is being processed on the production line. This is an outcome of the various talks I had with the employees of the washing line. In this research we will also use a separate part: the Maintenance KPIs. Because you're dealing with waste it is better to separate them. Standstill can come about due to an impurity that can be fatal to a part in the machine. Further details will be discussed in the maintenance KPI part.

- **Quality**

  Quality KPIs are related to the quality of the end product and the output of the input product.

- **Energy**

  Energy KPIs are related to the amount of electricity that is used to produce the end product. In this research it will be defined differently. It will be defined as all the inputs, or energy, that goes into the process to come about the output. These KPIs are for a sustainability analysis and financial calculation very useful.

4.4.2 Equipment KPIs

The production line of Rodepa can be seen as one machine or equipment in this case. Because it is a continuous flow production process. The whole production, the HKW and the FWL, are harmonised and the shredder stops if the washing line is too full.
So these KPIs are not as relevant for this project and are similar to the Process KPIs. The equipment KPIs are mostly about efficiency, capability and utilisation of a machine, instead of looking at the whole production process. The equipment KPIs, described in the research, will also be considered as Process KPIs.
The equipment KPIs are more focused towards a specific machine in the production line. Due to technical difficulties, complexity of the production line and time constraints I won't be taking the specific machines of the production line into account.

4.4.3 Measurement Elements

In order to calculate the KPIs, we have to use and gather the right measurements. This is where the measurement elements are used for. According to the ISO 22400 [7], these elements can be defined as: "relevant measurements for use in the formula of a key performance indicator". The elements are measured in time and quantity. In the article they define that the production data, related to the amount of output, often is generated after it has been handled by the logistical part of the company. Company X works the same. The big bags are weighed after they have tapped off and then the time is registered. So this is a problem to keep in mind. KPI Scope The scope of this research will only be on the HKW and FWL production lines, so we won't be considering KPIs related to logistics or personnel.

4.4.4 Maintenance KPIs

The input of the HKW and the FWL are called waste for a reason. A load of plastic waste, as can be found in the plastic bales waste characteristic, could also contain contaminants as metals and stones. The metals and stones also come in different shapes and sizes. There have been several instances that a piece of metal has jammed the shredder and thus stopped the whole production line for several hours.
Under Maintenance KPIs, which we have subtracted from the article mentioned earlier, we can define the failures. When a piece of metal jams the production line, it can be seen as a failure. So these will be useful in this research, if tailored to correctly to the need of my research.

4.5 Selecting KPIs from Literature

All the KPIs mentioned in the articles found in the literature study, are in Appendix **??** Literature Review according to the theoretical framework. The KPIs that are most relevant to the production process and that can be calculated with the available tools, are mentioned.

4.5.1 KPIs not considered

The KPIs related to the utilisation of the production line won't be considered. This is due to the variability in the input, because the waste is not made to order, and the unavailable data about the planned throughput rate.
The KPIs related to the planning of the production line won't be considered. This is due to the deviation in the time in which they plan production batches and the actual time batches are produced. This is because of the way they plan the production and the available production related data.
We also won't be using Inventory and Logistical KPI, as mentioned earlier.

4.6 Outcome Systematic Literature Review

The duplicate KPIs, that were found during the KPI gathering process, are removed from the list. And also the KPIs are removed due to reasons mentioned earlier. In the tables: 4.5,4.7, 4.6 below an overview of KPIs can be found. The list can be found in table A more elaborate list can be found in **??**.

Table 4.5: Overview of Process KPI extracted from the Literature Review

Process KPIs

Production	Quality	Energy
Allocation ratio	Actual to scrap ratio	Comprehensive energy consumption
Allocative efficiency	Emission / Produced output	Energy Consumption
Availability	Fall of ratio	Energy input / Produced output
First pass yield	Finished goods ratio	
Line throughput rate	Finished goods ratio	
Percentage actual uptime	First time quality	
Production process ratio	Integrated goods ratio	
Setup ratio	Other loss ratio	
Throughput rate	Percentage of full quality product	
	production loss ratio	
	Quality buy ratio	
	Quality ratio	
	Raw-material input / Produced output	
	Rework ratio	
	Scrap ratio	
	Waste deposit / Produced output	

Table 4.6: Overview of Measurement Elements extracted from the Literature Review

Measurement elements	
Time	Quantity
Actual busy time	Actual production
Actual downtime	By-product quantity
Actual order execution time	Comprehensive energy consumption
Actual production time	Conveyor speeds
Actual unit busy time	Desired quantity
Actual unit delay time	E.G. heat transfer rate of heat exchanger
Actual unit down time	E.g. Number of valve openings
Actual unit idle time	E.g. Vibration amplitude
Actual unit processing time	Energy medium quantity
Actual unit setup time	Equipment production capacity
Blocking time	Failure event
Corrective maintenance time	Good part
Failure event	Good quantity
load	Input Quantity
Operating Hours	Inspected part
Operating speed	Integrated good quantity
Operating time between failures	Lower specification limit
Preventive maintenance time	Other loss
Process cycle times	Output quantity
Process setup times	Planned scrap quantity
Resource mean time between failure	Process scrap percentage
Resource mean time to repair	Produced quantity
Startup	produced quantity in the first operation process
Starving time	Production loss
Time to failure	Raw Material Quantity
Time to repair	Resource/process energy consumption
	Rework quantity
	Scrap Quantity
	upper specification limit

Table 4.7: Overview of other KPIs, s.a. Equipment KPIs and Maintenance KPIs, extracted from the Literature Review

Other KPIs	
Equipment KPIs	Maintenance KPIs
Allocation Efficiency	Corrective maintenance ratio
Allocation ratio	Equipment ware
Availability	Maintenance costs / Produced output over a time period.
Blockage ratio	Mean delay time
Buffer capacity	Mean operating time between failures
Critical machine capability index	Mean time to failure
Effectiveness	Mean time to repair
Equipment load ratio	Number of alarms over a time period
Fall of ratio	
Machine capability index	
Mean operating time between failures	
Mean setup time	
Net equipment effectiveness	
OEE	
Overall Equipment effectiveness	
Percentage production rate of max rate	
Production process ratio	
Setup ratio	
Starvation ratio	
Technical efficiency	
Utilization efficiency	
Work in process	

4.7 Outcome Systematic Literature Review

The KPIs that are selected for the final use will be discussed in Chapter 7.

Chapter 5

Measurement Plan

This is the approach to measure all parameters relevant to the HKW and FWL. The scope of the measurement plan is on the HKW or FWL.

Goal

The goal of this measurement plan is to come up with a plan that is easy to carry out, without disturbing the process and putting excess pressure on the operators. Thus attractive for businesses to carry out.

5.1 Index Of Measurement Plan

1. Preparation of Measurement
2. Incoming Material
3. Before Measuring
4. Start Measurement
5. During Measurement
6. End Measurement

5.2 People Actively Involved in Measurement Plan

A list of people involved in the measurement. They are actively involved in the Measurement Plan.

1. Measurer in Charge, Task:
   (a) Makes sure all the tasks are performed correctly.
   (b) Makes sure the data, that is needed, is collected.
   (c) Is responsible for the whole measurement.

2. **HKW only:** Forklift Operator 2, Task:
   (a) Moves, empties and weighs: Additives + Waste Bins + all Big Bags.
   (b) Write down the times of a performed task and the thrown in bales.
   (c) Also deliveres the correct bales to the HKW.
3. **FWL only:** Forklift Operator 4, Task:
   (a) **Disclaimer:** Not the forklift operator that is part of the washing line shift, but part of the extruder line production.
   (b) Makes sure the Silo, in which the end product of the FWL goes, is tapped off and the end product of the FWL goes into the Big Bags.
   (c) Makes sure the big bags are weighed and the weight is written down on the data sheet and on the sticker.
   (d) Moves, empties and weighs: Additives + Waste Bins + all Big Bags. (Sometimes also for the HKW)
4. **FWL & HKW :** Forklift Operator 1, Task:
   (a) Delivers the correct bales to the FWL and HKW. Makes sure the bales are weighed and the weight is written down on the data sheet and on the sticker.
   (b) Removes and collects iron wires

   Disclaimer: Task:
5. **FWL only:** Forklift Operator 3, Task: **Disclaimer: Crane Operator**
   (a) Throw in the Bales in the production line.

5.3 Preparation of Measurement Plan

The following tools have to be present:

1. Stopwatches/Clocks
   (a) Function: In order to keep track of time all the tasks that are performed, such as throwing in bales, electricity consumption, weighing of IBC's and VARIBOX-es etc. and comprise them in a timeline.
   (b) Amount that have to be present: 1
      i. 1. For Measurer in Charge
2. Electricity Measurement Device.
   (a) Function:

i. Shredder: In order to measure the true time the production line is in use and in which states the machine is. (For definition of states see 1. Production Line description - States)
Measurement interval: 1/2/5/10 Seconds.
   A. Device HKW: Chauvin Arnoux. (Not present on machine, still to be installed)
   B. Device FWL: Chauvin Arnoux. (Not present on machine, still to be installed)
   C. Installation: Appendix MD.

ii. Full Production Line: In order to measure the total electricity consumption, such that we can calculate the total costs of 1 Kg of end product.
Measurement interval:
   A. Device HKW: Schneider (Already Present)
   B. Device FWL: SocoMec (Already Present)

3. Moisture and Temperature Measure App:
   (a) Function: In order to measure the effect that the temperature outside the production hall has on the water consumption and possible has on the electricity consumption.
   (b) Amount that have to be present: 1
   (c) App: Buienradar.nl
   (d) This is currently not used in this research.

4. Industrial Weighing Scale.
   (a) Function: In order to measure the weight of the bales, IBC's, VARIBOX-es, Big Bags on which we perform a measurement.
   (b) Amount that have to be present: 1
   (c) **Disclaimer:** there is already one present, but it has to function in order to measure the weight. If there is no way of measuring the weight, then we cannot perform the measurement.

5. Stickers/Labels for the bales.
   (a) Applying: these have to be applied by the forklift operator, when the load arrives.
   (b) Function: In order to label all the bales of the resource input, that is going to be used in the measurement.
   (c) Production Line: Both FWL and HKW
      i. Disclaimer: Not Performed when there is a bulk delivery for the HKW.

5.4 Incoming Material

Before performing the test, you have to consult with the people, responsible for a certain task in the measurement, upfront and make sure they perform their task and know exactly what is expected from them.
Disclaimer: The people responsible for the task have to be preferably the same persons every measurement. This is because people **subjectively** grade freights differently.

1. **A Freight** has to be selected for the measurement.
   (a) Reason:
      i. In order to compare freight with each other.
      ii. In order to be able to get the
   (b) Responsible for this task: Lab/Measurer in Charge
2. **The Sample** has to be categorised, in order to characterise the freight
   (a) Reason: In order to categorise a freight, you have to subjectively grade the sample. This way we can expect the effect that a freight has on the performance of the production line.
   (b) Responsible for this task: Lab/Measurer in Charge
   (c) Reference: Incoming Freight Report
   (d) Amount of input that has to be present:
      i. Both weights are determined by the supervisors.
         A. FWL: 10 ton of resource input.
         B. HKW: Whole Load.
3. **Applying Stickers:**
   (a) Reason:
      i. The production staff can find the bales that will be used in the measurement.
4. **The Weight Ticket.** This is a task that is performed, separate from the Measuring Plan.
   (a) Reason: This is to measure the amount of material, or resource input, that is being processed by the production line.
   (b) Responsible for this task: Reception

5. **Pictures of the resource input have to be made.** This is a task that is performed, separate from the Measuring Plan. In the picture the sticker with the reference number has to be visible.

   (a) Reason:

      i. It gives an indication of the size and the surface size of the material. Bigger material takes longer to shred to a certain size, compared to small material.
      ii. It gives an indication of the type of material that is being processed. If it has, for example, a lot of contamination and what form of contamination.
      iii. For future references, so that freights with similar production performance can be optically compared and similarities can be found.

   (b) Responsible for this task: Reception and Forklift Operator.

5.5 Before Measuring

The following tasks have to be performed and completed before the measurement actually start, with a **minimum of 15 minutes.** The Incoming Freight Report has to be fully filled in before starting the measurement.

5.5.1 Installation Measurement Equipment

The following equipment have to be installed or present before starting the measurement.

1. **Electricity Measuring Devices** has to be installed. See Appendix : Guide - Electricity Measuring Device for the installation guide. K.1

   (a) 10 Minutes before the production or batch run start, turn on the device and start the measurement. Or set up the time on the measurement device, such that you it will start automatically 10 minutes before the measurement.

2. **Synchronize all clocks.** The clocks that will be used during the batch have to be on the same time or the difference in time has to be noted down.

   (a) Reason: minimize the deviations of the time registration of the clock of the Measurer in Charge.

   (b) This is especially usefull when performing a time series analysis.

   (c) The following clocks are used:

      i. Gage Clock: Device of the Measurer in Charge
      ii. Electricity Measurement Device

3. **Weighing Scale has to be present and working**
    (a) Disclaimer: As mentioned earlier, already present.
4. **Stickers applied**
    (a) Check whether stickers are applied.
    (b) Check if the applied stickers, have the reference number of the measurement that you perform.

5.5.2 Stand-0

With Stand-0 we mean the basis on which we start all measurements. This is the most important part, in order to get objective and reliable measurements. This way we can determine the effect of a resource input on the washing lines. And also the effect of different machine settings on the measurement.

The batch, where the measurement is performed on, has to be from one freight from one supplier. The bales used during the test have to fulfill these criteria.

1. Reason:
    (a) The freight can be traced back to a weighing ticket, s.t. the total input material can be easily weighed.
        i. The weighing ticket gives us the total amount of resource input.

5.5.3 Stand-0: Reset

The production line has to stop producing output, no material in the bunker, no material in the waste bins and no material in the output big bags. This is when a new batch run can start.

1. The shredder blades have to be new. The first time the blade shred material is during the measurement.
    (a) Reason:
        i. The wear of the shredder blade, has an influence on the output. The wear is also dependent on the performance of the shredder.
        ii. There is a correlation between the wear of the shredder blades, the hours a screen has not been cleaned for and the shredder throughput rate.
2. The Screens have to be cleaned before a measurement. The first time the cleaned screens are used is during the measurement.

(a) Reason: There is a correlation between the hours a screen has not been cleaned for and the shredder throughput rate.

3. Empty all waste containers.

   (a) Reason:

      i. So we can estimate the total waste production of a resource input or batch, by starting of with empty waste containers.
      ii. Water and leftover waste for the previous batch can still have an influence on the measured amount of waste, because there is still some left in the waste bin.

4. The bunker has to be empty (Specific for HKW/FWL) of material from the previous batch or freight can be present.

   (a) Reason: Minimize the effect of the leftover material from the previous batch has on the production line.

5. The machine has to produce no output from the previous freight/batch for about one hour. It is still producing output, but not at the peak rate as when input is still being added. With output is meant waste still falling in the waste bins and end product still falling in the big bags.

   (a) Reason:

      i. Get an accurate measurement of the total output, by minimizing the amount of material left from the previous freight and still in the system.

6. For the FWL and HKW: The PolyAanmaakUnit has to be filled to the top. See Appendix PolyAanmaakUnit K on how to fill the unit. The weight of the bag, after the PolyAanmaakUnit has been filled back up, should be registered.

   (a) Reason:

      i. This way we can monitor the total consumption of the PolyAanmaakUnit.
      ii. This is in the current not considered for both production lines, because the consumption is mimimal.

5.5.4 Stand-0: Registration

First write down the name of the Measurer in Charge on the Incoming Freight Report .
This has to be done before the start of the measurement:

1. Weigh all VARIBOX-es and IBC's with additives.

(a) Reason: So the consumption of additives can be measured during a production run.

2. Write down the Water meter level of the washing line. Of both the Source meter and the Vitens meter. This is beginning level with is used to calculate the water consumption.

    (a) Reason: The total water consumption of the washing line can be determined this way.

3. Write down the Temperature outside the washing line hall itself. This can be done with Buienradar.nl.

    (a) Reason:

        i. This has an influence on the water consumption of the washing line, because the temperature has influence on the amount that evaporates during the process.
        ii. This has an influence on the weight of the bales. Bales can suck up water such that is increases the weight of the bales, thus have an effect on the input to output weight ratio.
        iii. This is not considered in the current measurement.

4. Moisture level of the past 4 days. This can be done with via Buienradar.nl.

    (a) Reason: This is to establish a relationship between the moisture in the freight, the weight of the freight, weight of the output.

    (b) The interval at which a measurement has to be performed is.

    (c) This is not considered in the current measurement.

5. Write down the Standing on the Electricity Meter (kWh). See Appendix Electricity Measurement PlanK on how to measure the standing on the electricity meter.

    (a) Reason: Measure the total consumption of the washing line. As a check on the measured electricity consumption.

6. For FWL only: The silo has to be empty and there can be no end product left from the previous batch.

7. For HKW only: The big bags, both of the waste and end product, have to be new and empty.

    (a) Reason: Same as point 1. Get an accurate measurement of the total output of a batch, by minimizing the amount of material output from the previous freight.

With old Shredder Blades.

8. Write down the Amount of hours the screen have worked before starting the measurement.

   (a) Reason: The amount of hours that the screen have worked has an influence on the throughput rate of the production line.

9. Write down the Amount of hours the shredder blades have worked before starting the measurement.

   (a) Reason: The amount of hours that the blades have worked has an influence on the throughput rate of the production line.

5.6 Start Measurement

This is the actual start of the measurement. The following tasks have to be performed when the measurement is started. It starts when the resource input, on which you want to perform the measurement, is inside the bunker and the first resource input is put in the production line.

1. Start with the Electricity Measuring Device. 15 Minutes before the production or batch run start, turn on the device and start the measurement.

   (a) Subtract 15 minutes from the time at which a production run is expected to start.

   (b) Add 1 day to the time at which a production run is expected to end.

2. Write down Actual Start Time (First input time) on the Incoming Freight Report from the Gage Clock.This is when they actually start with the production process.

   (a) Definition of Actual Start Time: The time at which a bales is thrown in the shredder.

   (b) Reason: This is for the calculation of one of the KPIs.

3. Measure the time the first time output estimation comes out of the production line. **Definition of First time output:** This is the moment when there is a peak in output of the washing line, of the batch on which the measurement is performed, goes into the bigbag of the HKW or comes out of the tube at Extruder 4 for the FWL.

   (a) Reason: This is for the calculation of one of the KPIs

   (b) Difficulty: Both washing lines are a continuous flow process. So to determine this time is very difficult. This can only be estimated.

5.7 During Measurement

This is the time between the Start Measurement and the End Measurement. These are tasks that are being done regularly with an interval specific to the FWL and HKW.

Measurements that are performed, when the bins are full:

1. Measure the weight of the waste bins, when they're full.

   (a) Reason: The total waste production of the bales can be estimated.

   (b) Time Frequency: **whenever a waste bin is emptied and at the end.**

2. Measure the weight of the Big Bags, when they're full.

   (a) Reason: In order to calculate the final weight of the end product.

   (b) For HKW: There are 2 types of Big Bags,

      i. End product: this is the product that is targeted to be extracted from the waste.

      ii. Foil waste: This is collected by the suction device and is regarded as waste or by-product of the HKW depending on the quality.

   (c) For FWL: The foil goes straight to the Silo during the production run. At the end of the production run the foil, the end product, will be extracted from the Silo and put in big bags. The big bags with the end product will be weighed at the end **OR** they can be weighed during the measurement

5.8 End Measurement

5.8.1 Requirement for calling it the End of a production run:

1. The production line has to produce no end product or output from the current freight/-batch for one hour.

   (a) Reason: Get an accurate measurement of the total output of a batch, by maximizing the amount of material output from the current freight.

2. The bunker has to be empty:

   (a) Reason: Make sure that all the input of the batch has been used, in order to minimize the deviation for the actual Resource input to Resource output ratio.

If these conditions are fulfilled, then start with the following tasks.

5.8.2 Final Registration

1. Write down the Water meter level of the washing line. Of both the Source meter and the Vitens meter. This is beginning level with is used to calculate the water consumption.

   (a) Reason: The total water consumption of the washing line can be determined this way.

2. Measure the weight of the IBC and the weight of the all the VARIBOX.

   (a) Reason: So the consumption of additives can be measured during a production run.

3. Write down the Temperature outside the washing line hall itself. This can be done with Buienradar.nl.

   (a) Reason:

      This has an influence on the water consumption of the washing line, because the temperature has influence on the amount that evaporates during the process.This has an influence on the weight of the bales. Bales can suck up water such that is increases the weight of the bales, thus have an effect on the input to output weight ratio. This is currently not considered during the measurements.

4. For FWL only: Weigh the total end product of the FWL.

   (a) The foil goes straight to the Silo during the production run. At the end of the production run the foil, the end product, will be extracted from the Silo and put in big bags. The big bags with the end product will be weighed at the end.

   (b) Make sure the the Silo is empty and no more end product comes out of the FWL.

5. For HKW only: Weigh the last big bags hanging still in the production line.

   (a) The big bag, which contains the end product from the batch on which the measurement is performed on, have to be weighed.

   (b) The big bag, which contains the foil from the batch on which the measurement is performed on, have to be weighed.

   (c) Reason: Get an accurate measurement of the total output of a batch, by minimizing the amount of material output from the previous freight.

6. For the FWL and HKW: The PolyAanmaakUnit has to be filled to the top again. The weight of the bag, after the PolyAanmaakUnit has been filled back up, should be registered.

(a) **Reason:** This way we can monitor the total consumption of the PolyAanmaakUnit.

(b) **Disclaimer:** it is not considered in this research, because the consumption is hard to measure.

The following is currenlty not considered:

1. **Actual time the last input was thrown:** This is when the forklift operator puts an input, of the batch on which the measurement is performed, in the production line for the last time.

   (a) Reason:

      i. This is to calculate a KPI.

      ii. To test whether there is a deviation in the throughput rate when the system is running at a certain capacity.

2. **Actual time the last output comes out**: This is the moment when the last output of the washing line, of the batch on which the measurement is performed, goes into the big bag of the HKW or comes out of the tube at Extruder 2 for the FWL.

   (a) Reason:

      i. The production produces output consistently produces output and waste for more than 1 hour after the last bales was thrown in. It will make the measurement plan a lot more expensive.

   (b) Reason it's not considered:

      i. This time is hard to establish because it is a continuous flow process. The production line will slowly decrease it's output. The production is never fully empty, there is always something left. Otherwise it would be a good indicator to find out how the production process behaves when it is performing at a higher capacity.

5.8.3 Measurement Devices

1. Compare all clocks used with the Gage Clock. If there is a deviation, then register it.

   (a) Reason: This is a check to make sure that you're measurements are accurate and the time registered have not changed.

2. Collect all papers:

   (a) Incoming Freight Report

(b) Production sheets Data

3. Download data Electricity Measurement Device.

4. Receive Report from Lab.

5.9 Measurement Intervals

This part is about the measurement intervals that are used in the measurement plan:

1. **Standing at the beginning of measurement & Standing at the end of a measurement:**
   These measurements are done at the beginning and at the end of the measurement, as is mentioned in the description of the measurement plan.

2. **1/2/5/10/20 Seconds Interval**
   These intervals are done with the use of a measurement device. The intervals are limited by the software and the device itself. The specific measurement device has a limited memory to store the recorded data, so the measurement interval is dependent on the expected length of the measurement.

3. **Variable: Full Waste Bin & Variable: Full Big Bag**
   The interval at which a waste big or big bag is full, depends on the resource input. The time that is written down on the data sheet, is the time that a big bag or waste bin is weighed.

5.9.1 Reasoning For Intervals

Water Consumption, Electricity Consumption of the total washing line, additive consumption and the waste production can be measured more than once. This can be interesting if you want to a time series analysis.
But in consultation with the company supervisor, the interval found above has been determined for these measurements. The drive behind this these measurement are financial and operational.
An overview of the intervals can be found in table 5.1

Financial: Addition Costs

Performing a measurement brings addition costs, that are added to the operating costs of the washing line. Additional time has to be invested in to perform the measurement. There are extra handling tasks that has to be performed by the operator. For example, to get the Stand-0, as it's called in the Measurement Plan, extra handlings have to be performed.
And the extra interval measurement mean extra handling. So extra costs have to be made in order to get these interval measurements.

Operational: Workload and Pressure

And performing the measurement also puts more pressure and workload on the operators. The operation has to continue as normal, but extra handling have to be made for the Measurement Plan. If you want to do more intervals, such as weighing of the additive containers, the waste containers and output, then you would have to do more handlings. The production has to be at a normal speed to make sure that results are representable. Electricity and water standings can be registered, during the measurement. But this requires addition tasks of the Measurer in charge, which is a time consuming.

Support Data

Also there is no properly timed data to support it. This is for example the exact time a big bag of the HKW is full. The time that is registered is the time that a big bag is weighed. This can be linked to the Kg of the big bag, the ampere level of the shredder and to the electricity standing, if the time was registered otherwise.

Electricity Measurement

The electricity measurement device for the shredder, with which we determine the up- and downtime of the production line, was already present. And installation is relatively easy, with the help of experienced and licentiate personnel. So doing an interval measurement with a programmable interval is easy.

Continuous Measurement

Continuous interval measurements can be done, but this requires a big investment in automation. The weighing can be done automatically, electricity consumption can be done automatically, water and additive consumption can be done automatically with a more frequent interval.

Table 5.1: An overview of the Measurement Intervals

Nr.	Measurement	Interval
1	Water Consumption	Standing at the beginning and end
2	Electricity Consumption Total Washing Line	Standing at the beginning and end
3	Additive Consumption	Standing at the beginning and end
4	End Product	Variable: Full Big Bag
5	HKW: Foil Production	Variable: Full Big Bag
6	Waste Production	Variable: Full Waste Bin
7	Electricity Consumption Shredder	1/2/5/10/20 Seconds. Depends on the\ length of the measurement.

5.10 Implementation of Plan

In this part I will discuss the employees necessary, in order to carry out the measurement plan. The measurement requires coördination and communication, in order to be carried out properly.

5.10.1 Overview Preparation Measurement

1. Back Office Commercial Assistant

   (a) Task to Perform:

      i. Freight Arrival: He is responsible for the planning of the incoming freight. In order to find out when the freight will arrive, you have to confer with them.

2. Measurer in Charge

   (a) Task to Perform:

      i. Freight for MP: they decide on which freight they want to perform a measurement.

3. Management/Purchase-Department

   (a) Task to Perform:

      i. Freight for MP: they decide on which freight they want to perform a measurement.

4. Electricien/ Qualified Mechanic

   (a) Task to Perform

      i. Installation Electricity Measurement Device: in order to measure the needed production time, you have to install the electricity Measurement Device.

5. Production Planning

   (a) Task to Perform

      i. Confer with them when a freight will be processed, so that you can plan the Before Measurement part of the plan. And also prepare the operators needed in the During Measurement part.

5.10.2 Overview Before Measurement

1. Reception

   (a) Task to Perform:

      i. Weighing Receipt: At the reception there is a weighing bridge, in which they weigh of the loaded and the unloaded truck.
      ii. Incoming Freight: When a freight arrives, then the first step for it is to pass the reception in order to check the document. The can inform you, that the freight has arrived in order to perform an Incoming Freight Report on it.

2. Production Chef

   (a) Task to Perform

      i. IFR: this report is made by him, upon arrival or just before the start of the measurement.
      ii. Selecting Bales for MP: advises with the selecting process.
      iii. Inform Operators: responsible for letting the operators of the FWL or HKW when an MP is coming.

3. Measurer in Charge

   (a) Task to Perform:

      i. Incoming Freight Report: Help the production Leader with it.
      ii. Measurement: responsible for writing down the water levels and electricity standings.

5.10.3 Overview During Measurement

1. Forklift Operator HKW or FWL

   (a) Task to Perform

      i. Stand-0: responsible for this part of the measurement as described in the MP.

      ii. Data Registration: he is responsible for the registration of all outputs as described in the MP.

1. a. i. ii.

5.10.4 Overview After Measurement

1. Lab Personnel

   (a) Task to Perform:

      i. Carrying out test to establish the quality of the output, such as impact strength, MFI, Color Specification, DSC and moisture.

5.11 Possible Threats to Validity - Weight (or Angle Share)

In the whiskey industry, there is a well-known phenomenon: "the Angle Share". This is the share that "vanishes" over the process of aging. A certain percentage of the whiskey is absorbed by the barrels. Thus the amount of whiskey in the same barrel decreases over the year, due to evaporation.
The definition of the Angle Share in this research is the following: The missing weight, when subtracting all input form all outputs. This is the weight that also vanishes.

5.11.1 The Angle Share can be influenced by the following:

Moisture/Water in Resource Input

1. (a) There is a certain amount of moisture in the resource input. This amount has an affect on the resource input weight and thus on the efficiency of the resource output. In both production lines there are machines that separate the moisture from the plastic during the processing and thus vanishes this weight.

2. **Absorbed by Water - Other Liquids**

   (a) In the waste, for example in post consumer waste, there can still be a bottle of liquid inside the bale. This is due to a sort error in the waste sorting centre. The liquids in the bottle will be carried away by the water into the water treatment or into the sewage.

3. **Absorbed by Water - Other Substances**

   (a) In this process, you're dealing with waste that is contaminated with surface contamination. For example, the leftover butter in a cup. This contamination is washed off during the process.This will also be carried away by the water into the water treatment or into the sewage.

4. **Sludge Production**

   (a) There are 2 lines, the HKW and the FWL, that produce Sludge. The Sludge production of the HKW and the FWL produce one final Sludge stream. The throughput time of the sludge is also unknown. So this hard to measure and in this configuration can't be estimated.

   (b) There is also a seperate unit placed for both the HKW and FWL, that also produces sludge. The throughput rate of the sludge is unknown so it is hard to estimate this.

   (c) This is not considered in the measurement. It is not a part of the waste share.

5. **Polymere Unit**

   (a) There are 2 lines, the HKW and the FWL, that use a Polymere additive. It is hard to estimate this, because over the course of a production run a small amount is consumed.
   This amount can be influenced, when filling the unit back to the top. When compressing the additive, you get a false measurement. The consumption can be a discussion point, because there is no data to estimate the throughput rate of the water in the water treatment.

5.11.2 Deviation in Waste Measurement (Also Influence on Angle Share)

Moisture/water in Waste Bins

1. (a) The washing process is very water intensive. A big part of the waste that is being carried away is with the help of water.
   There are de-watering channels in the final waste bin, that carries away the water by the canals in the production hall. The weight of the waste is continuous decreasing depending on the moisture content.

2. **Continuous flow Process**

   (a) The production process, both the HKW and the FWL are never fully empty, because the production process is a continuous flow. There is always some contamination or end product stuck for example in the water, or not flowing at the rate that the other waste has. This can be of both the previous freight and the current freight.

5.11.3 Possible Threats to Validity Time

Grinding Determines Pace of Shredder

1. (a) The electricity consumption of the Shredder is used to determine when the production line is on or off, and when the shredder is busy or starving. This determines most of the production time related data and calculation of certain KPIs. If the Grinding Mill has to give too ampere, it will automatically shut down the shredder. This can't currently be filtered out of the electricity measurement. And is something to keep in mind, when processing the electricity measurement data.

Chapter 6

Key Performance Indicators Measurement Plan

This part is the KPIs that can be used for the input and the production line.

6.1 KPIs of Input

6.1.1 Subjective test

As mentioned in the part: Quality, it is very hard to look inside a bale of plastic waste. But based on the experience of the production personnel, they are able to give their own marks to the freight. With the help of a subjective and non-complicated scoring system, it can be possible to characterise a freight. The relevance still has to become clear in the course of time In this part the different types of contamination, that you will find in plastic waste, will be categorised.

6.1.2 Scoring Scale

With the help of the production leader of the washing lines, a scoring scale will be added for these types of contamination. The idea behind it, is that the production leader has the most experience with subjectively grading freight.
Second, he has to perform these tests. The test can only be properly performed if he stands behind the grading sheet. And a way to encourage this, is to develop it with his help.
The scoring categories, supporting the different categories of contamination and of mechanical properties, can be found in part below. The scoring scale is established in conference with the production leader.

Disclaimer:

1. The tests are subjective, due to the fact that there are no methods to establish the amount of contamination or input characteristics. The amount of moisture, sand and other contamination, can be determined, but they would be relatively time consuming

and expensive. Possible measurements are not considered in this research, due to a time constraint.

2. The plastic bales are still waste, so there could be for example a waste bag full of silicone straps or a bag filled with PET bottles inside a clean looking bale. The filtering process doesn't work properly if there is a huge amount of silicone straps or bag filled with PET bottles at once. As mentioned earlier, the outside appearance of the bale can deceiving.

6.1.3 Contamination is Loss

When you're buying resource input, recyclers are partly buying a resource that they consider as waste them self. During the washing process, contamination such as sand and stones are washed off. The more waste in contained in the bales, the more they pay for 'waste'. Waste in this case, is also for the recycler considered waste, because they cannot sell it or add value to it and turn it into a product.

6.1.4 Technical Difficulties Testing Quality

There are several technical difficulties, when doing sampling testing on the resource input. The main difficulty is, that you're dealing with resource input that is purchased to go over a washing line.This means that there is too much contamination be processed on the extruder without causing the extruder to breakdown.
There are also no methods or to objectively say something about the type and amount of contamination. For example to establish the amount in Kg of sand in a bale. Next to that, it is not profitable to do these tests for both the supplier and the recycling company. All these tests are done subjectively and only objective tests on output of the washing lines are done. This makes it difficult to do objective testing about for the resource input. Some testing on the output of the HKW and FWL is done, but not enough to establish the increase in quality of the resource input.

6.1.5 Scope of KPI

The scope of theses KPIs will be about the resource input. The input that is meant as input for the HKW or FWL.

6.1.6 Threats to Useability and Viability

1. **Usability -** The usability of this report has to become clear over the course of the data gathering process. Possible failure to this report could be that the report takes too much time to do and thus is not carried out.

2. **Viability -** Whether this report has an added value to the measurement plan, has to become clear of the course of the data gathering process.

6.2 Input Related Characteristics

There are different characteristics of plastic waste, that have an effect on the performance of the production process. With these characteristics, an indication can be done about the expected production costs. The quality of the end product of the washing lines, has to be compared to similar products. This way you can establish a price for the end product and establish the added value to the resource input. Scoring Sheet can be found in Appendx Incoming Freight Report.

6.2.1 Type of Plastic

The main characteristic of plastic waste. When buying plastic waste, it is often characterised as one type of plastic. This may vary in practice, depending on the supplier. The definition of main plastic is the plastic that has been bought in. Small table overview can be found in table 6.1.

Table 6.1: Type of Plastic

Nr.	**HKW + FWL**
1	Give description of main type of plastic
2	If necessarry: Description of second type of plastic

6.2.2 Origin

The origin of waste often has an indication of the amount of contamination there is in the resource input. There are 6 categories in characteristic.
Company waste are often mono streams, and come directly from a company. The company that produces a product, that generates a waste streams. Due to a short cycle of waste from product to being regarded as waste to the recycler, it is easy to establish the used additives and so the potential to recycle the waste. And also the amount of contamination is often minimal, due to the short cycle.
This list is tailored to the needs of Rodepa and can be expended, when there is a need for it. The list can be found in table 6.2

6.2.3 Homogeneity in Material

According to the lab of Rodepa, it is easier to estimate the characteristics of a mono waste stream, for example waste flower pots, than from a multi waste stream, such as post consumer waste. There is more homogeneity in a mono stream, than in a multi waste stream. You can still say something about the possible mechanical aspects of the multi source resource input, but it is harder than with a mono steam.
This is due to the fact that a mono stream, as the name suggests, is mainly one product that has consistent mechanical properties throughout the load. This can often give a good

Table 6.2: List of all relevant streams for Rodepa

Nr.	Name	Description
1	Post Consumer (Multiple Streams)	Often derived from the orange container, as it is known in the Netherlands. It is a sorted fraction.
2	Post Consumer (+ 3 or less streams)	Often derived from relatively mono streams, for example PET bottles. They are collected, sorted and separated.
3	Post-Industrial (Mono)	Waste that comes about as a direct effect of the production process. E.g. Cutting loss of a product. Often relatively clean stream, without to many contamination.
4	Post-Industrial (Multiple Streams)	Waste that comes about, not as direct effect of the production process. Often unsorted fraction, that is a reject from the clients of the supplier.
5	Agri	Waste that comes from the agri-industry. E.g. potting soil plastic bags, plastic around bales of hay.
6	NA	Combination of all kinds of waste. Not possible to categorise it.

indication about the impact strength for example throughout the freight, with which you can estimate the throughput rate.
A mono waste stream is for example a freight with black flower pots and terra flower pots. The definition of mono waste stream in this case is the product of the same kind. This does not depend on the color or colors that the freight has.

In table 6.3 is an overview with the combination of waste streams that a resource input can consist of.

Table 6.3: Overview of all Relevant Streams

Nr.	FWL + HKW	Description
1	Mono Stream	Often derived from the orange container, as it is known in the Netherlands. It is a sorted fraction.
2	2 Mono Streams	Often derived from relatively mono streams, for example PET bottles. They are collected, sorted and separated.
3	3 Mono Streams	Waste that comes about as a direct effect of the production process. E.g. Cutting loss of a product. Often relatively clean stream, without to many contamination.
4	Multiple Waste Streams, more than 3 Mono Streams	Waste that comes about, not as direct effect of the production process. Often unsorted fraction, that is a reject from the clients of the supplier.

In table 6.4 is an overview with the amount of foil that a resource input for the HKW can have.of the number that an amount of foil.
Within the washing process, there is a drying process in which the end product is mechanically dried. After the drying there is separation process where light materials, such as foil, is separated from the end product. Depending on the different types of foil, can this by product be profitable.

Table 6.4: For HKW only: Contamination Streams of By-Product in HKW

Nr.	HKW: Foil Separator
1	No Foil
2	Little amount of Foil
3	Medium amount of Foil
4	Big amount of Foil

6.2.4 Homogeneity in Color

The coloring of the regranulate happens by Rodepa or the customer. And as mentioned earlier, in order to get a certain color specification, you need a regrind or granulate that is already that color specification. Or has a color specification with which you can reach a certain color specification. The more homogeneity there is, the easier it is to estimate whether it can reach a certain color specification.

Seasonal Effects

Throughout the year there are seasonal effect, that can cause the resource input to have a fluctuating color specification. For example, there are suppliers that deliver a more black resource input in the summer than in the winter. This is due to the fact that there are more flowers sold in the summer and those flowers are often in black flower pots.

The color specification of the regrind has an influence on the price. For example white regranulate is more expensive than black. Because you can make white regranulate from less resource inputs than black regranulate. White can only be made from white, while black can be made from a combination of different colors. And from white regranulate you can make more colors than from black.
There is no way to color regranulate or regrind that is black. And if they color all white regrind or granulate black, then there will be no white left in the future. Rodepa can add more value the end product by adding a color separator to the process and extract all the different colors from the process.

In the tables 6.5 and 6.6 below, you can find the different color specification that the resource input can have.

1. **Example HKW:** Household with a lot of different colors of cups, plates and bottles. This is given the grade 3-1.
2. **Example FWL:** White foil with a small amount of colored material, for example some blue foil. This is given the grade 1-2.

Table 6.5: For HKW only: Color Specification of Resource Input with corresponding number

Nr	HKW	Contamination of Colored Material
1	White input	No contamination
2	One Non-Black Color Input (e.g. red/blue/green etc. flowerpots)	Small amount of Non-Black Colored Material
3	Mix of Different Colors Input	High amount of Non-Black Colored Material
4	Black Input (e.g. Black Flower Pots or Black flower pots with terra colored flower pots)	Not Used

Table 6.6: For FWL only: Color Specification of Resource Input with corresponding number

Nr	FWL	Contamination
1	White foil	No contamination
2	Trub Natur foil	Small amount of colored foil
3	One Color Foil	High amount of colored foil
4	Mix of Different Colors Foil	Not Used
5	Pure Black Foil	Not Used

Attention: If there is a small amount of colored foil in the for example white foil. Then it will be graded: High amount of colored material. This is due to the fact that black has a lot of effect on the color of the end product.

6.2.5 Impact Strength or Toughness

This is an item that depends on the homogeneity of the input resource. According to the production leader, it is still doable, to get an indication about the impact strength or toughness of the resource input, depending on the incoming freight. Sometimes it is not doable, because of all the different materials contained in the freight.
The impact strength of the resource input is related to the throughput rate of the production line. The shredder and grinding mill performs well on material that is high in impact strength. The production leader can guess, based on his experience, with relatively good precision how long it will take to process an entire load and thus how he will produce an hour. The used definition of Kg per hour, is the amount of end product per hour.
More data regarding the impact strength of the resource input, and the impact strength of the output has to be gathered in order to establish a relation. The impact for the resource input is measured in Kg of output per hour.
In table 6.7 below you can find the Expected throughput rate linked to a number. The impact test of the output can be measured with the Charpy Impact test, for which the lab has sufficient means to perform such a test. The measurement is noted in lost energy per unit.

Table 6.7: Expected Throughput Rate Corresponding to Number

Nr.	**FWL**	**HKW**
1	- Confidential - Kg per Hour	- Confidential - Kg per Hour
2	- Confidential - Kg per Hour	- Confidential - Kg per Hour
3	- Confidential - Kg per Hour	- Confidential - Kg per Hour
4	NA: When recieving for example a 324 freight, there is a lot of deviation in the type of material that is contained in the freight. This makes it impossible to estimate the throughput rate.	**NA**

Disclaimer: The HKW shredder will be replaced by a different shredder, so the output of the HKW will also be different. These scores will also be changed.
Disclaimer: Kg per hour doesn't link to the volume that is produced, due to the density of different products that can be processed. So the amount of volume per hour can be the same for a certain product, but the amount of kg per hour won't be the same.

6.2.6 Size of Material

The overall size of the material determines how fast it falls through the screen of the shredder and grinding mill. Big material takes longer to shred to a certain size, before it falls through the screen. Small material is shredded faster to a certain size and falls faster through a big size screens. This has an effect on the throughput rate of the shredder, which affects the throughput rate of the whole production line. An overview with examples can be found in table 6.8.

Table 6.8: HKW & FWL: Size of Resource Input

Nr.	Size	Examples
1	Small	Plastic Caps (fall easily through the screen)
2	Big	Cups, Margarine, Container, Flower pots (requires more processing, before falling through the screen)
3	NA	Multiple waste streams, too much deviation in the size of the materials. For example Household waste with bottles, cups etc.

6.2.7 Thickness Material

The thickness of the material has effect on the contamination that a freight can hold and gather. The thinner the material, the more surface area it has and the more potential it has to store contamination. So there is a linear relation between the thickness of the material and the amount of contamination. This holds for both the inputs of the FWL and the HKW. And the thickness of the material also has an effect on the throughput rate. More elaborate explanation can be found in Input Contamination Categories - Thickness Material. This category is especially useful for the FWL. The scores with examples can be found in table 6.9 and in table 6.10.

Table 6.9: Thickness Indicator for HKW

Nr.	Thickness	Examples
1	Thin	Cups, Margarine Container, Flower pots
2	Thick	Plastic Caps
3	NVT	Multiple waste streams, too much deviation in the size of the materials. For example Household waste with bottles, cups etc.

Table 6.10: Thickness Indicator for FWL

Nr.	Thickness	Examples
1	Thin	Stretch Foil
2	Thick	Shopping bags, Shrink Wrap, Siegel folie
3	NA	Multiple waste streams, too much deviation in the thickness of the materials. For example HouseHold waste stream.

NA: If the resource input consists of too much different waste, with too much deviation in thickness of the materials in the waste. Then it has no use to asses the freight on the thickness of the material. This is left up to the judgement of the production leader.

6.2.8 Moisture

As mentioned earlier, the moisture content in the resource input, has an effect on the weight of the resource input and on the Angle Share. This is a contamination for which you also

payed, because you pay per kg of resource input. The amount of moisture can be influenced by the weather, due to rainfall during transportation, or due to the origin of the waste. It is not possible to objectively measure the moisture content of a bales, due to technical issues mention earlier.
In table 6.11 an overview of the score can be found.

Table 6.11: Overview of Moisture Content

Nr.	Moisture Content	Examples
1	None	Left to the subjectivity of the production leader or measurer
2	Moist	
3	Wet	
4	Sooking Wet	

6.3 Input Contamination Categories

These categories have been made in accordance with my supervisors and the production leader. They relate to the contamination that can be found in plastic waste. A distinction is made between plastic waste of the HKW and FWL. The amount of contamination in plastic regrind, that hasn't been filtered out, has a negative effect on end quality and process ability of the plastic output.

Scope of Categories

The scope of these categories will be about the resource input. The input that is meant to go over the HKW or FWL.

6.3.1 Overall Contamination or Freshness

This is the main category for contamination. Further in this chapter, we will elaborated on the subcategories of contamination. It can give a good indication of the quality of the resource input. But this doesn't necessarily mean that the amount of input relative to the output is preferable or that it won't cause any problem during the processing. You're dealing with waste so there are uncertainties that could cause standstill or an not so favourable input relative to output.
In table 6.12 an overview can be found with a corresponding number.

Table 6.12: Overview of score with freshness or overall contamination

Nr.	Freshness	Overall Contamination
1	Good	No Contamination
2	Medium	Small Contamination
3	Bad	Medium Contamination
4		Big Contamination

6.3.2 Metal Contamination

Metal Contamination is pieces of metal of different sizes throughout the freight. This can be a pull tab from a can, screws, bolts up to crankshaft from engines and metal wires. And the metals can be also different e.g. aluminum stainless steel. This material is for the most part filtered out in the float-sink tank of the process.

Breakdown Process

Depending on the size of the metal pieces, it could have a negative influence on the process and cause a standstill in the process. It could clog and cause the shredder to breakdown. Depending on the size of the pieces it could break the cutter blades and damage other parts. Finding some metal in the bales could give an indication that there are bigger pieces in the bales.

Extrusion Process

If there is a big amount of metal in the plastic waste then it is harder to wash it off, which has a negative effect on the quality of the regrind used in the extrusion process. It can pollute the filter of the extruder, which causes it to filter less effective. There is a linear relationship between the effectiveness of the filter and the pollution in the filter of the extruder. It could also cause the filter to break.

Injection Process

If there are big metal particles present in the regranulate, then it could also clog the mould of the injection molding machine of the customer. In an injection mould process, the material flows through nozzles into the mold and the size of the nozzles can be so small that the contamination gets stuck. It causes the process to breakdown. This depends on the machines that the customer uses.

Scoring: NVT

Reason: Very difficult to say, due to the fact that small pieces of metal are hard to detect or see in a bales of plastic waste. And one relatively small piece of metal in one of the bales could cause the production line to fail. If there is metal found in the bales, then the freight will be rejected and won't be process on the line.

6.3.3 Sand Contamination

With sand is meant sand, concrete rest, stones of different sizes. It is filtered out in the float-sink tank and the friction washer for the most part and washed off.

Water System

If there is too much sand in the plastic waste, then it will cause clogging in the water system and clogg the whole process. Which causes the process to come to a standstill. This depends on the amount of sand contamination, it could collect in the circulating water tank and contaminate the water. This also has a negative effect on the effectiveness of the water in the washing process.

Breakdown Process

Depending on the size of the sand, for example stones, it could cause the shredder to breakdown. It has the same effect on the washing process as mentioned in the part Metals Contamination and cause a standstill. Extrusion Process If there is a big amount of sand in the plastic waste, then it has the same effect on the washing process and on your regrind as mentioned in the part Metals Contamination. And how much is filtered out during the extrusion process is depended on the filter size of the extruder. Fine sand, for example, is hard to filter out It causes spots in the end product of the customer.

Injection Moulding Process

If there are still big sand particles present in the regranulate, then it has a negative effect on the quality of the customers product. It leaves marks of the remaining sand in the product. Depending on the size of the sand could also cause the injection moulding machine to breakdown, as mentioned in the part Metals Contamination.
Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big
Reason: On the outside you have a relatively good view of the amount of sand contamination there is in the bales. The sand is often distributed throughout the bale and can be seen on the outside.

6.3.4 Organic Contamination

Organic contamination is often garden or agri-waste e.g. plants, flowers, grass, algae, wood etc. This is contamination that is hard to wash off during the process. The leftover contamination on the regrind sticks and cakes to the extruder screw. Which has a negative effect for the end quality of the product after the extrusion process. This is because the caked contamination breaks off at some point in the extrusion process and comes in the end product. This give spot in the end product.

Water System

Too much organic contamination could cause the water tubes to clog, as mentioned in the Sand Contamination part.

Injection Moulding Process

If there are still big organic particles present in the granulate that are not filtered out in the washing process, then it has the same effect on the injection moulding process as mentioned in the part Metals Contamination. This has an effect on injection. It could cause spots in the end product.

Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big

Reason: On the outside you have a relatively good view of the amount of organic contamination there is in the bales. The organic contamination is often distributed throughout the bale and can be seen on the outside.

6.3.5 Paper Contamination

With paper contamination is mentioned paper stickers and among other things paper flyers etc. For the most part paper is filtered out during the washing process. The paper contamination that is left on the regrind, are for the most part paper vibers. These fibers can be found back in the end product and causes spots the plastic becomes weaker.

Water System

Paper also pulp in the process, which contaminates the water that is used in the process. It causes the additives to be less effective in washing process.It also cloggs the water pipes, which causes standstill during the process similar to Sand Contamination.

Extrusion Process: Lignin

Paper contains lignin, which contains the fibers of wood together. Lignine changes color when it is affected by UV-light and also by heat in the extruder screw. The paper contamination, such as stickers, can change the color of natural foil to a slight brown or yellow natural foil.

Extrusion Process

Paper stickers and plastic stickers, common in foil waste, are hard to wash off during the process. And the leftover paper stickers cakes to the extruder screw in the extrusion process. This has the same effect as mention in Organic Contamination.

Plastic Stickers

Plastic stickers are homogenized in the extrusion process. This is the case with stickers of the same polymer. For example a PET stickers on a LDPE bottles causes disturbance in the extrusion process. The filter of the extruder will be filled faster and causes more downtime, as mentioned below in the part Other Plastics - PET.

Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big

Reason: On the outside you have a relatively good view of the amount of paper contamination there is in the bales. The paper contamination is often distributed throughout the bale and can be seen on the outside.

6.3.6 Other plastics

PET Pure PET, for example bottles and salad boxes, is filtered out during the washing process. This is due to the fact that pure PET sinks in water.
If it is multi layered, for example plastic LDPE bottles with PET stickers, then it is still filtered out by the extruder filter. But it causes the filter to fill up quickly. If the filter is full, they have to shut down production in order to change the filter which is a time consuming task, between half an hour up to 2 hours. PET also causes gels, which will be further explained in the part PET/PA/EVOH.

Mixture PE/PP

The customer desires an end product which often has a certain MFI specification. They can control this MFI during the extrusion process with the use of an additive.
This additive causes PE regrind to crosslink and make a connection between two polymer chain, so that the MFI drops. With PP regrind it breaks the connection of two polymers, so that the MFI raises. These additives counter each other, such that it will be very hard to produce an end product with a certain end specification.

PVC

Most known PVC product is PVC tubes. PVC products are filtered out in the washing process.
If PVC where to get in the extruder then it would start to decomposition.In this phase chlorine and hydrochloric acid gas is released. These gasses are sucked away in the extruder and thus removed from the end product. But it is harmful for the employees and for the environment. And Hydrochloric acid gas affect the metal of the extruder, which causes it to rust. This rust will affect the end product. The rust can be found back in the regranulate.
The gas that is released could cause the so called: “gas grain”. This is when grain contains gas on the inside or is hollow on the inside. When the customer, for example a flower pot producerer, uses the regranulate in their extrusion process, then it causes holes in the flower pot. This is because there is gas or air on the spot where there should be regranulate. This also depends on the specification of the extrusion process of the customer.
During the decomposition of the PVC product, it becomes solid at some point. Depending on the amount of PVC that is in the extruder, it could clog the whole extruder and stop the extruder. It takes a lot of effort and man power to unclog the whole system.

PET/PA/EVOH/Silicone

Gels, which are spots in regranulate or in the end product of the customer, are soft spot of contamination that are caused by polair plastics. PET, PA and EVOH plastic are polair polymers and cling together during the extrusion process because of a dipole moment. These plastics cling to each other to form gels and do not cling to PE, which is a apoliar polymer. They negatively influence the quality of the product. It has influence on the appearance and probably some on the mechanical properties.

Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big

Reason: On the outside you have a relatively good view of the amount of, for example, PET contamination there is in the bales. The paper contamination is often distributed throughout the bale and can be seen on the outside.
Disclaimer: The plastic bales are still waste, so there could be, for example, a waste bag full of silicone straps inside. The filtering process doesn't work properly if there is a huge amount of silicone straps at once.

6.3.7 Additives in Plastic

Plastic has a big variety of applications for which it can be used. This is due to the fact that there are different additives available to give a desired property for an end product. There is, for example, a flame retarding additive that are in military materials such as canvas tenting. The additive makes the tents less likely to catch fire. There are also financial incentives for adding additives to virgin polymers. Polymers are in their pure form relatively expensive and the price can be lowered by adding additives. For example, by adding chalk to the polymer, that is used in plastic cups, you can lower the price of the end product. In this case it also give a desirable property to the product, because it becomes more sturdy.
Certain additives could start to degass or cause gels during the extruding process and influences the quality of the end product in a negative way. It could cause for example "gas grain" as mentioned earlier. Homogeneity of Resource Input Depending on the homogeneity of the resource input, it is possible to get an indication of the additives used. For a homogeint resource input and mono waste stream is relatively easy to establish the used additives. This can be because the supplier of the waste provides the info. And also because there is a lot of experience at Rodepa to get a good guess. Then they can judge the recyclability of the input.
Post Consumer waste, in the Netherlands it is waste that is disposed in the orange container, has a big variety of plastics. The availability of different additives is big and applied in a lot of different products, it is not possible to determine the additives used. The possibilities to determine the additive in the plastic is limited and often not profitable. They can determine the amount of additive used.

Scoring: NVT

Reason: This is something that is usefull for in the future, because it has an effect on the deployability for a certain end-product in the extrusion process. And does not neccesarrly have an effect on the washing process.

6.3.8 For FWL only

These categories are only applicable for the FWL.

Chalk In Foil

This is for foil especially an important additive contamination. Too much chalk in the resource input foil makes it so that you cannot be sealed. This is a property that is essential for foil. If there is too much chalk in the foil, than it can only be used for casting foil.
Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big **Reason:** Chalk foil is lighter than water, so during the float-sink part of the washing process it will be filtered out. So this has an influence on the waste production.

Chalk On Foil

Too much chalk on foil itself is damaging for the machines. It will start to thicken the material and the water. It will start to cling together and form one big ball of plastic, such that is will . This is also true not only for chalk, but also for milk powder. **Scoring:** 1. Nothing - 2. Little - 3. Between - 4. Big
Reason: Chalk will be washed off during the washing process, but it will start to thinken

Ink

Plastic foil is often printed with advertisements, warnings and other prints. Every inkt, that is used is different per print, thus the amount of metals in the inkt varies.
For example heavy metals in ink could gas a lot of gas in the extrusion process. Depending on the homologation temperature of the ink, most of the degassing happens in the cutter of the extruder, before it goes in the extruder. The lower the homologation temperature of the ink, the more of the degassing happens in the cutter. Degassing of the input in the extruder causes, as mentioned earlier, ‘gas grain’.

Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big
Reason: This has no influence on the washing process, but does have an effect on the extrusion process. This is something to discuss in the future.

Color with Ink

Prints on plastic bags have a variety of colors and prints differ in size. Prints of plastic bags as shown in the picture, can be very big or very small, for example the zipper logo on the transparent foil. And as mentioned earlier, the color is homogenised to one color. Depending on the amount of print present in the plastic waste and depending on the different colors present the plastic waste, a color specification for an end product can be made.
Inkt still causes gels in the end product, which has a negative effect on the quality.
Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big **Reason:** The plastic foil, that is processed on the FWL, doesn't have a lot of ink inside. Second, the amount of ink on the plastic foil doesn't have an effect on the FWL.

Contamination in Natural Foil or White Foil

Natural Foil is a transparent foil that has a big application due to it transparency. It can make a big range of color specification, if desired, depending on the desired end product. Other colored foil between the natural foil can cause it to change color and lose it transparency fully or to a certain degree.
The same is true for white foil. If there is too much black foil between the white foil, then you can't extrude a certain white specification foil from it. Or you can't reach the desired color specification that is needed for a certain end product.

Scoring: Mentoined ealier in Input Related Characteristics Homogeneity in Color
Reason: Difficult to say, but doable. On the outside you have a relatively decent view of the amount of colored foil contamination there is in the bales. The effect of the colored foil, depends on the different colors of foil.

Stretch foil

Stretch foil is often tough, very thin and transparent foil. It is very hard to shred and get a decent output on the shredder. It is a very well known problem in the plastic recycling industry.
Stretch foil has a good stretch, as the name suggests, and can store a lot of energy. It is more likely to stretch out, than to break upon impact. It can wrap around part of the machines in the production line. It warps for example around the transportation screws in the FWL, such that it causes standstill in the process.
Stretch foil sticks, during the shredding, to the end point of the blades of the shredder, mill and cutters. This will make the blades less effective and the throughput rate will drop.
Scoring: 1. Nothing - 2. Little - 3. Between - 4. Big
Reason: On the outside you have a relatively good view of the amount of stretch foil contamination there is in the bales. The stretch foil contamination is often distributed throughout the bale and can be seen on the outside.

Transparent Foil: 98/2 - 95/5 - 90/10 - 80/20 - 50/50

Same as described in chapter 4.

Trub Natur A or B

- confidential -

Thickness Foil

Foil has a variety of thickness, then there is relatively more surface area on which contamination, such as sand and organic material, can stick to. So the thinner, the more sand, moisture and other contamination can be in between the foil. This is also the case with Stretch Foil.
Thin foil is often also lighter than normal foil, which causes it to fly up in the shredder of the FWL. This causes the throughput of the process to be lower, because it is harder for the shredder to get a grasp on the material in order to shred it.
Scoring: Mentioned Earlier in Input Related Characteristics – Thickness of Material.

Laminated Plastic

Laminated plastic is plastic film that consist of multiple layers of different plastics, or a combination of plastics with other substances, such as wood, paper or fabric. These plastics are often very hard to recycle properly without decreasing the quality of the extruded end product. This is due to the fact that the different layers are very hard to mechanically separate from each other.
The different types of plastics in the laminated foil could case. Due to the fact that mixing certain types of plastic causes it to decrease the quality of the extruded end product, due to e.g. gels, or makes it harder to get produce a specification for an end product. This is the case with PE and PP for example. A production related example of a laminated plastic is the plastic LDPE bottle with the PET sticker, as mentioned earlier.
According to the study, the only laminated foil that can be recycled, without causing the plastic to decrease in quality is window film.
The **definition** used in this research, is the laminated foil that is considered contamination. So laminated plastic that cannot be processed profitable and that has an negative influence on the quality.
Score:1. Nothing - 2. Little - 3. Between - 4. Big – 5. N.A.
Reason: This doesn't have an effect on the washing process, but it does have an influence on the extrusion process. Depending on the homogeneity of the resource input, you can say something usefully about the processability of the resource input.

Mechanical Properties Output to Measure Input

The resource input of the HKW or FWL, due to the technical difficulties mentioned earlier (KPIs of Input - Technical Difficulties Testing Quality) can't be measured objectively. After the washing process, there is an opportunity to do the following objective test. Because the resource input is clean enough to be used in the extruder, testing plates can be moulded and tested.

With these tests you can get a good indication for which end product it can be used. This also gives an indication to the mechanical properties of the resource input.

Customers often require a specification that meets a certain impact strength or MFI specification. This information is very useful in order to estimate proportions needed in the extrusion process, in order to get the desired specification. The same goes for the impact strength, MFI and for the color specification.

Below you find the most common properties that are used to determine the use of the regrind in a certain end product.

Objective Measures Performed on Output:

1. Impact Strength: This test differs from the Impact Strength KPI of the resource input, because this test is measured in J/m2.
2. Tensile Strength: This test differs from the Tensile Strength KPI of the resource input, because this test is measured in kg/cm2.
3. MFI
4. Color Specification: only performed if there is an interest for a certain color specification.
5. DSC: in order to establish the purity and quality of the end product.
6. The end product also consists of a certain amount of moisture. The moisture is also part of the end weight of the total end product.

The specification of the test, such as the unit of measurement, can be found in chapter Quality 3 and Appendix D.

Chapter 7

Key Performance Indicators for Washing Lines

The list is made according to the framework found during the literature study, see appendix C and chapter 4. It is tailored to the needs of the HKW and FWL. The measurement elements needed for the KPIs are categorised according to black box method described in chapter 2: Production Line. The use of this

ISO-Norm KPIs

The KPIs deviate from the KPIs as described in ISO norm 22400-2. This is due to the fact that the ISO document is not available to me. WIth the help of the documents found in the literature study, some KPIs were derived. In appendixE , you can find the used documents. This is the reason that the definition of the KPIs in this research can deviate from the KPIs found in the ISO document. See table 7 for an overview. The format for defining KPI is the one used in ISO 22400-2:
Name: (KPI) - Category Theoretical Framework

1. Description:
2. Scope:
3. Formula:
4. Unit of Measure:
5. Range:
6. Trend:

Scope of KPI

The scope of these KPI will be about the performance of the production process. The production process in this case is limited to the HKW or the FWL.

Equipment KPIs

As mentioned in the chapter 4: KPIs, we won't be considering the Equipment KPIs. This is due to the fact that the production process is a continuous flow. It is not possible to check the quality of the product between the different machines in the washing process.
The whole process at Rodepa consist of 1 or 2 processes: the washing process and the extruding process. But due to time constraints and due to the complexity of both lines, we won't be considering the different machines.

Disclaimer: Full description of KPIs with calculation can be found in Appendix E.1: Overview all KPIs used for FWL and HKW.

7.1 List of Input Quantities

Below you find a list of the inputs that the washing lines consumes. We are considering all elements of the blackbox as mentioned in the production line description, together with the elements of the measurement plan. The input are all the input that are needed in order to get a useable output.
Short overview of the Quantity Measurement Elements related to the input can be found in table 7.1.

Table 7.1: List of all the input Quantities

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Quantity	Input Quantity Electricity
2	Measurement Element	Quantity	Input Quantity Resource
3	Measurement Element	Quantity	Input Quantity Additive
4	Measurement Element	Quantity	Input Quantity Source Water
5	Measurement Element	Quantity	Input Quantity Vitens Water

7.2 List of Output Quantities

Below you find a list of the output that the washing lines produce. This includes the use able product quantity, by-product quantity and waste quantity. A graphical representation of what an input consist of, after it has been processed by the washing line, can be found in table 7.3. In the Appendix E.1 a more elaborate list can be found.
Short overview of the Quantity Measurement Elements related to the output can be found in table 7.2.

Table 7.2: List of all the Output Quantities

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Quantity	Product Output Quantity
2	Measurement Element	Quantity	Foil Output Quantity
3	Measurement Element	Quantity	Waste Output Quantity
4	Measurement Element	Quantity	Slik Output Quantity
5	Measurement Element	Quantity	Angle Share Quantity

Table 7.3: Graphical Representation of Input divided into Output

Resource Input Quantity			
Product Output Quantity	Waste Output Quantity	Foil Output Quantity	Angle Share Quantity

7.3 Additional KPI: Maintenance - List of Failure Event - Measurement Elements

Upon dealing with plastic waste, there is a change that the process come to a hold due a fatal pieces of contamination coming into the production line. The contaminants that could cause the process to come to a hold is described in the part KPIs of the input. The production process could also come to a hold due to technical difficulties. For example a water tube that breaks or a bearing that is worn out.
In order to properly establish the quality of the resource input, you have to separately consider the failures that are caused by the input and other failures. This way you can say partially something about the quality of input from a supplier.
The distinction will be discussed further below.

7.3.1 Failure Event Occurrence - Measurement Element - Quantity

Description: The amount of failures events that occur during the production process. There is a distinction between a failure event caused due to technical difficulties and a failure event caused due to the input.
This distinction is also used in with the KPIs:

1. Name: Failure Event Occurrence Production Related

   (a) Description: Mentioned earlier. For example: a water tube that is broken or the forklift is broken.

   (b) Scope: HKW or FWL

(c) Formula: The frequency that a production line is down due to technical failures.

(d) Unit of Measure: Integer

(e) Range: NVT

(f) Trend: The higher the frequency, the more often the production line is interrupted.

2. Name: Failure Event Occurrence Input Related

(a) Description: Mentioned earlier. Example: a piece of metal that causes the shredder to come to a halt.

(b) Scope: HKW or FWL

(c) Formula: The frequency that a production line is down due to input related failures.

(d) Unit of Measure: Integer

(e) Range: NVT

(f) Trend: The higher the frequency, the more often the production line is interrupted.

7.3.2 Name: Failure Event Time - Measurement Element - Time

The amount of time that the production process is down due to a failure event.
The starting time is the moment that the process comes to a hold due to a failure event.
The end time is the moment that the failure is fixed and the process is starting back up.
Again a distinction between the 2 types of failures is made.

1. Name: Failure Event Time Production Related

(a) Description: Mentioned earlier.

(b) Scope: HKW or FWL

(c) Formula: As mentioned above: Start Time Production Failure Event - End Time Production Failure Event

(d) Unit of Measure: Hours:Minutes

(e) Range: NVT

(f) Trend: More time means that the production line is down.

2. Name: Failure Event Time Input Related

(a) Description: Mentioned earlier.

(b) Scope: HKW or FWL

(c) Formula: As mentioned above: Start Time Input Failure Event - End Time Input Failure Event

(d) Unit of Measure: Hours:Minutes

(e) Range: NVT

(f) Trend: More time means that the production line is down.

7.3.3 Failure Event Type

There are different events that could the process to come to a standstill. The events can be categorised, due to the frequent occurrence. Again the failure events are divided into 2 categories.
Failure Events due to failure of Production Line. Every machine in the production line has a change to break down and cause the production line to come to a hold. This is often due to general usage of the machine and wear and tear.

The failure event can be described as followed:

1. Machine Number

   (a) The machine number of a machine in the production line can be found in the Appendix A.

2. Failure Event : Machine Related Failures

   (a) Periodic Maintenance Failure: e.g. Worn Out Gearing, Broken Gearing

   (b) Preventive Maintenance Failure: e.g. Full Screen, Cutter Blades Worn out

   (c) Electrical Issue: e.g. blown fuse, broken frequency controller, broken cable.

   (d) Non Maintenance Related Failure: e.g. Broken Water Tube,

3. Non Machine Related Failures

   (a) Employee Related Failure: e.g. Breaking a piece of equipment by an employee.

   (b) Equipment Related Failure: e.g. Breaking Down of a forklift.

Example: The friction washer of the HKW has a broken gearing 2.40 - 1

Failure Events due to Input

As mentioned in KPI for Input, you are dealing with contamination in the waste that can cause the process to come to a halt. The following could be the cause of that.

1. Metal:
    (a) E.g. pieces of metal that breaks the shredder blades
2. Small Sand Particles:
    (a) E.g. Sand in the circulating water tank of the FWL. This is due to the fact that there is too much sand in the input material that the filters couldn't filter it out of waste water.
3. Big Sand Particles:
    (a) E.g. Stones or piece of concrete that breaks the shredder blades.
4. **For FWL only:** Stretch Foil
    (a) Foil that wraps around a transportation screw s.t. the process comes to a halt.
    (b) If this happens, write down the number of the machine as described in the Appendix A Production Line Description.

7.3.4 List of Production Related Time

All the measurement related to the production process of the HKW and FWL. These elements help with the calculation of the KPIs.
Short overview of the Time Measurement Elements related to the production. See table 7.4 can be found below.

Table 7.4: List of Production related Time

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Time First Bale Thrown In
2	Measurement Element	Time	Time First Output Comes Out
3	Measurement Element	Time	Starting Time Production
4	Measurement Element	Time	Ending Time Production

7.3.5 Production Time Shredder

Below you find a list 7.5 of elements in which you characterise the shredder times. It refers to the time that a shredder is in a certain state.

Table 7.5: List of Production Time of the shredder

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Starting Time Production
2	Measurement Element	Time	Ending Time Production
3	Measurement Element	Time	Up Time Shredder
4	Measurement Element	Time	Down Time Shredder
5	Measurement Element	Time	Starving Time Shredder
6	Measurement Element	Time	Busy Time Shredder

7.3.6 Production Time Measurement Elements

Below you find a list 7.6 of elements that are necessary to determine the production time. These production time are related to the whole production line, the HKW or FWL, including the shredder.

In the figure 7.1 you can find a graphic representation of the build-up used for the production time related measurement elements.

Assumption: Rebuilding time is considered in this research and will be registered. Every rebuild is considered to take the same amount of time to complete. The Total Shift Time and the Actual Production Time does include the rebuild time. The Actual Unit Production Time is considered to be without the rebuild time.

Disclaimer: Planned Down Time is already excluded from all Measurement Elements.

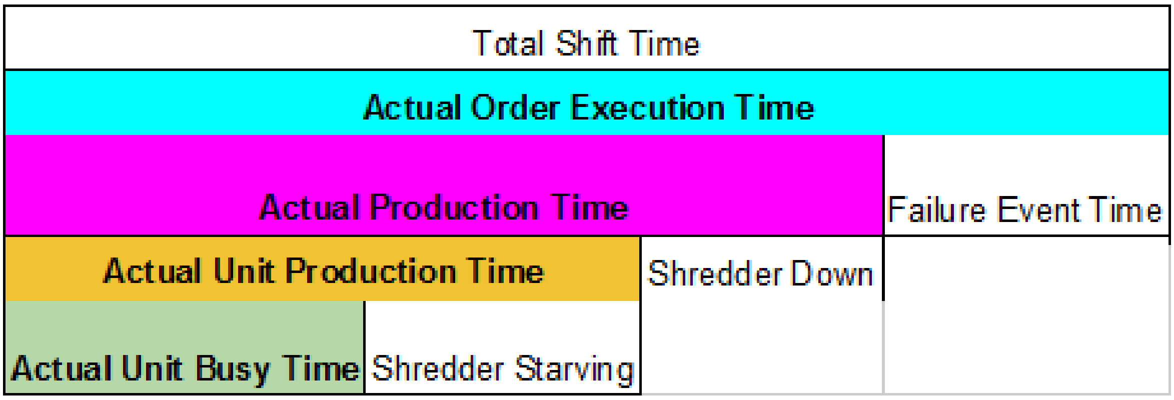

Figure 7.1: A graphic representation of the different production time elements

Table 7.6: Overview of Measurement Elements related to the production times

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Actual Order Execution Time
2	Measurement Element	Time	Actual Production Time
3	Measurement Element	Time	Actual Unit Production Time
4	Measurement Element	Time	Actual Unit Busy Time
5	Measurement Element	Time	Time Last Output Is Thrown In
6	Measurement Element	Time	Time Last Output Comes Out

7.4 Process KPIs

In chapter 4 is the definition of process KPIs and the 3 subcategories: Production KPI, Quality KPI and Energy KPI. In addition to that, you find the maintenance KPI. In the table 7.7 below you find a small description of those KPIs.

Table 7.7: Overview of used Theoretical Framework

Name	Description
	Process KPIs
Quality KPI	All KPIs related to the output.
Energy KPI	All KPIs related to the input that is needed in order to get an end product.
Production KPI	All KPIs related to the performance of the production process.
	Maintenance KPIs
Maintenance KPI	All KPIs related to the Failure Events of the production line.

7.4.1 Quality KPI

These concern the KPIs related to the quality. This can be related back to the resource input that has been processed. In table 7.8 you find the used KPIs.
The waste ratio used in this category can be related to the KPI Ausbeute, that is known within the company.

Table 7.8: Overview of the used Quality KPIs

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Quality	Quality Ratio
2	Process KPI	Quality	Waste Ratio
3	Process KPI	Quality	By-Product
4	Process KPI	Quality	Angle Share
5	Process KPI	Quality	Slik Ratio Data

7.4.2 Energy KPIs

These KPIs concern the Energy Consumption. The defnition of Energy is: The resources needed to create the final end product of the washing line. The water ratio can be divided into 2 subcategories: Vitens Water and Source Water. In the table 7.9 you find an overview of the used KPIs.

Table 7.9: Overview of the used Energy KPIs

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Energy	Electricity Ratio
2	Process KPI	Energy	Additive Ratio
3	Process KPI	Energy	Water Ratio
4	Process KPI	Energy	Water Ratio $\longrightarrow$ Vitens Water Ratio
5	Process KPI	Energy	Water Ratio $\longrightarrow$ Source Water Ratio

7.4.3 Production KPI

These concern KPIs related to production. In the tab 7.10 you find an overview of the used production KPIs.

Table 7.10: Overview of the used Production KPIs

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Production	Availability
2	Process KPI	Production	Allocation Efficiency
3	Process KPI	Production	Utilisation Efficiency

The utilisation could also be defined differently. The Actual Unit Production Time can't be calculated, so this static does not give usefull information. It could also be calculated as AUPT/AOET in order to give usefull information.

7.4.4 Throughput Related KPIs (Part of Process KPIs)

These are KPIs that are used to calculate the throughput rate and time.

Table 7.11: Throughput Related KPIs

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Production	Throughput Rate During Order Execution
2	Process KPI	Production	Throughput Rate During Shredder Running Time
3	Process KPI	Production	Throughput Time First Input
4	Process KPI	Production	Throughput Time During Shredder Running Time
5	Process KPI	Production	Throughput Time During Order Execution

7.4.5 Maintenance KPIs

These concern the KPIs related to the maintenance. The Failure Event Time Ratio can be divided into 2 sub-categories: Failure Event Time Ratio Production Related & Failure Event Time Ratio Input Related. And the Failure Event Occurrence can be divided into 2 sub-categories: Failure Event Occurrence Production Related & Failure Event Occurrence Input Related. In the table 7.12 you find an overview of the used maintenance KPIs.

Table 7.12: Overview of the used Maintenance KPIs

Nr.	Category	Sub-Category	KPI Name
1	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio
2	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio $\longrightarrow$ Failure Event Time Ratio Input Related
3	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio $\longrightarrow$ Failure Event Time Ratio Production Related
4	Maintenance KPI	Maintenance KPI	Failure Event Occurrence
5	Maintenance KPI	Maintenance KPI	Failure Event Occurrence $\longrightarrow$ Failure Event Occurence Input Related
6	Maintenance KPI	Maintenance KPI	Failure Event Occurrence $\longrightarrow$ Failure Event Occurrence Production Related

Chapter 8

Scoring & Ranking Suppliers

This chapter will be about the scoring and ranking of suppliers. This is where suppliers will get a grade, such that it can be compared to other suppliers or freights, and finally get a ranking.

8.1 Scoring

8.1.1 Definition: Quality of Waste

The following definition is applied, according to the article: “What is your definition of Quality”.
"Quality could be defined as a basic tool for a natural property of any good or service that allows it to be compared with any other good or service of its kind. The word quality has many meanings, but basically, it refers to the set of inherent properties of an object that allows satisfying stated or implied needs." [9]
This definition is used as a ground work for the quality, in order to compare freights with each other. The tool is the Incoming Freight Report, with appropriate properties. The good is regrind. This way a quality standard can established.

8.1.2 Goal

The goals of the scoring method is to compare freights from different supplier with each other on the basis of one handle: the added value. The added value is used to get a ranking of the different suppliers.

8.1.3 Effectiveness Washing Line

Quality of waste depends on the washing line that a company has. There is currently no handle or method on which a recycling company can determine the quality of waste and rank the suppliers. With a handle or a method they can compare load with each other in order to establish the quality.
The effectiveness of a washing line with removing certain contamination from the plastic

waste, depends on the washing lines. For example, one washing line can effectively remove labels from PET bottles, while other washing lines may not be able to do this, as mentioned earlier.
The effectiveness of a washing line in removing contamination determines the quality that can be reached with the extruded end product. The cleaner the washed product form the washing line is, the better the quality and the better applicable it is, the more valuable the end product will have. Thus the value added to the plastic waste is greater.

8.1.4 Added Value

The scoring mechanism will be based on the Value Added to the plastic waste. According to the Economic Census Manufacturing Series [10], the definition of value added is derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments (products manufactured plus receipts for services rendered).
In the measurement plan, all inputs and relevant costs to the production line are considered in order to establish the added value. We do not consider the overhead of the company. The shipment costs are not considered in this research to be a part of the added value.

8.1.5 Scoring Method: Financial Analysis

The added value will be determined with the use of the measurement plan, and thus the effectiveness of the washing line. Based on the outcome of the added value a score will be made.
The scoring will consist of 2 financial parts, the fixed and the flexible costs:

Flexible Costs

1. **Measurement Plan:** Total costs of the all Inputs, or materials and supplies: Vitens Water, Source Water, Electricity, Additives, Big Bags and Resource Input. These costs are elements, measured by the measurement plan.
   In this research the prices are based on the experience of the head sales.

2. **The average expected Selling Price of the end product** including the transportation costs. The average expected selling price is price in between the expected minimum and the expected maximum price.

   (a) **Discussion:** A more detailed look can be made in the total handling costs of a freight. The density of the produced output big bags and waste deviate per freight. Depending on the material, a full big bag can contain 600 Kg of material or close to 1000 Kg of material. The total handling can deviate per freight and thus makes it harder to produce at a certain speed.

(b) Reason: The value added to a resource product depends on the selling price of the end product.

(c) If the product is processed internally, then the selling price is based on the price, that the company would get if they to sell it to a customer. This has to be done preferably by the same person every time it is processed internally and in consultation with all sales personnel.

Fixed Costs

The following are considered to be over the time of one year in which the HKW is 48 weeks a year, 5 days a weeks, 16 hours a day in use. For the FWL it is 48 weeks a year, 7 days a weeks, 24 hours a day in use. If changed, it tis mentioned otherwise. This way the costs are relevant and only have to be adjusted yearly.
The current uptime of the HKW is 63 % and of the FWL is can't be calculated properly.
Important Assumption The calculation can be found in the appendix **??**.
In the fixed cost and Salary calculation we will make use of a 75 % uptime. The assumption that is used is that the striving up time of the shredder is 75 % procent. It is regarded that the 75 % is the up time in which the production line is producing output. The downtime is regarded with rebuilding time and down time due to maintenance.

3. **Overhead of the Production Line:** that has been budgeted for the year. These include: Operator costs, costs of the forklift, maintenance of the production line and all other costs related to the Production Line. Also the slik waste production and the amount of PolyAanmaak-additive consumption over a year.

4. **Failure Event Due to Input:** This can be divided into 2 sections:
The total amount of time of a failure event: This is the time that the production line is down, due to a failure event caused by the resource input.
The extra costs made to due to a failure event: These are the extra expenses that have been made to get the production line running after a failure event.

5. **Company Overhead:** that has been budgeted for the year. This includes all costs needed to keep the production lines running.
This is currently not considered, because they were not supplied in time.

Financial Analysis

More information on the financial analysis can be found in Appendix L. An costs analysis of the FWL can be found in table L.2. An costs analysis of the HWK can be found in table L.3. An analysis of the production costs can be found in L.5 for the HKW and in L.2 for the FWL. The scoring method will be based on all the costs made by the washing line, in order to create the washed end product.
We will make the added value calculation, based on this financial element. An overview of

the costs can be found in appendix L. This also includes the electricity documentation L.1 and the water cleaning bill L.2.

Important Assumptions

For the Disposal of water into the sewage, the company pays an fee per contamination unit. We assume that the distribution of the costs is the following:

1. A third of the costs for the FWL, a third of the costs for the HKW, a third of the costs for the Extruder Lines.
2. There are 2 operators for both lines, working a shift of 8 hours per day, 5 days a week.

Continuously Update

The cost calculation have to be kept up to date. This is because of the following reasons:

1. This way the scores can be compared and stay relevant over the total life span of the production line.
2. Over the time in which the production line is in use, all costs post can change significantly or differ from the budgeted costs. It is applicable for both the fixed and variable costs. The Balance between the different costs post can differ per year.
   For example, due to a new Collective Labour Agreement the costs of a hiring one employee increases significantly. This could mean that the original Freight Scores change significantly and other freights come out to be more preferable than before. This way you keep the scores up-to-date and relevant.
3. Purchasing and selling prices could change significantly due to change in for example regulations and market price. This has also an effect on the Freight Score.
4. New costs post could occur, for example the CO2-taxs. Depending on the product, this has also an effect on the Freight Score.

8.1.6 Quality Measure: Freight Score

The score that is hanged to the final score of a freight is called the **Freight Score**. This is in essence the value added per ton output, per hour of effective production time. In order to make a freight worthwhile, you also have to consider the output per hour that you effectively produced. In order to get an good overview of different perspectives of the added value, we also included: Value added, Value added per ton output, value added per ton input.

Worthwhile: Actual Unit Production Time + Failure Time Input Related

The time that is considered to determine whether a freight is worthwhile, is the Actual Unit Production Time + Failure Time Related to the Resource Input.

Failure Event Time Input Related The time that a production line is down is, is considered when determining the Freight Score. A failure could cause the line to stand still for a long period of time. Which in turn could cause the line to be non profitable. This is considered in the scoring, because the goal of this research is to rank supplier.

Throughput Rate: Per Ton Ouptput

The amount of end product that you produce in the time that the production line effectively produces is considered to be the Actual Unit Production Time. The more kg of output the production line produces per hour, relatively smaller the fixed costs become. This is because your selling price is also based on the price per ton.
In this research the AUPT is used, because it filter out the performance of the operator. It is also the easiest and cheapest ways to get precise data with a precision of 5 seconds. AUPT only consideres the time that the production line is producing, and thus not consider time spend on maintenance and rebuilding.

Freight Score

The Freight Score will be used to determine the quality and compare freights with each other.

Name: Freight Score (Value added per ton output per hour) - Process KPI - Quality

1. Description: The Value added per ton output per hour
2. Scope: From the resource input of the washing line until the output.
3. Formula: Value Added per ton output / (Failure Time Input Related + Actual Unit Production Time)
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: The more value is added relative to the input per hour.

An overview the KPIs and elements, s.a. value added, supporting the Freight Score, can be found in appendix E.3.

8.2 Ranking

The Freight Score is used to make a ranking of the suppliers. The ranking will consist of 3 parts the seasonality, technical innovations and the recent deliveries.

8.2.1 Technical Innovations

1. **Supplier:** The quality of the stream are also under the influence of technical innovations. For example, a sorting centre can apply a technical innovation to their sorting line, such that is produces plastic waste with a lot less foil. So the quality of the resource input improves, in comparison to the previous year. We consider it to be over the past year.

2. **Internally:** The washing lines are also continuously improved upon. Adjustments are made continuously, that will have an effect on the quality of the end product. These adjustments can make sure that they can better handle certain contaminations and thus add more value.
   Or the operators improve their production performance, such that the process becomes more profitable.

8.2.2 Seasonality

When dealing with plastic waste, you're also dealing with seasonality. Throughout the year the quality of the resource input deviates, as mentioned previously. The types of contamination and the degree of contamination can be vary throughout the year. This has to be considered when ranking the supplier. This is also something to consider over multiple years.

Discussion

The scope of this KPI can vary. It has to be adjusted based on the gained experience. Looking at the seasonality can be usefull for more or less than 2 month.

8.2.3 Deviation Past Deliveries

There can also be deviation in the quality of the deliveries. There can be, for example, 4 good sequential deliveries, and then 4 bad sequential deliveries. It can be be that the supplier has a problem in the production process, such that the quality of the resource waste is not what is expected. This has to be considered in the ranking system.

Discussion

The scope of this KPI can vary. For example, the scope can be 5 or 7 past freights. This has to be adjusted based on the gained experience.

8.2.4 Ranking System

There will be 3 ranking systems based on the 3 point discussed above, where the suppliers are compared with each other. The ranking systems are based on the **past 5 deliveries**,

the past year and the **past 2 month** from the previous year. These systems are made to deal with the deviation of the past deliveries, the technical innovations and the seasonality respectively. The supplier with the highest average score stand on spot one, and the others follow.

Past 5 Deliveries

This is the average Freight Score of a supplier based on the last 5 deliveries is considered. This is done to deal with the quality of the past deliveries. A description can be found below. For a less frequent supplier, it can also be altered.

Name: Average Freight Score Past 5 Deliveries - Process KPI - Quality

1. Description: The average freight score of the past 5 deliveries of one supplier
2. Scope: From the resource input of the washing line until the output.
3. Formula: Freight Scores Past 5 deliveries / 5
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: The better the score, the better the past 5 freights were.

Past Year

This KPI has been chosen to deal with the technical innovations. This is the average Freight Score of a supplier based on the past year that it has done. A description can be found below.

Name: Average Freight Score Past Year - Process KPI - Quality

1. Description: The average freight score of the past year of one supplier
2. Scope: From the resource input of the washing line until the output. Scope: From the resource input of the washing line until the output.
3. Formula: all Freight Scores Past Year / Amount of freight that year
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: The better the score, the better freights the past year were.

2 Month Previous Year

This KPI has been chosen in order to deal with the seasonality of the suppliers. The past 5 is chosen after a conversation with the purchasing personnel. This number can be changed when there is more data available.

Name: Average Freight Score 2 Months Previous Year- Process KPI - Quality

1. Description: The average freight score of the past 2 month, previous year of one supplier
2. Scope: From the resource input of the washing line until the output.
3. Formula: Freight Scores Past Year / Amount of freight previous year in those 2 months
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: The better the score, the better freights the past 2 month last year were.

8.3 Quality

Discussion about Quality

Quality is about comparing different score of contamination with the freight score. This way we can answer the question: "What is a good freight and what is a bad freight?"
For example, the different scores for contamination, need to have a weighing to them in order to see which categories are of a big influence on the freight score. This can only be done if there is enough data gathered, which is a time consuming task. And this can only be done over a longer course of time.

8.3.1 Recommendation to Establish Quality Standard

My recommendation is to use machine learning in order to establish the quality of plastic waste. You have to consider all elements from the Incoming Freight Report, and use it to estimate the expected F. reight Score. In machine learning you can see the weight of the different scores. This gives a good indication of what quality of plastic waste means. Over the course of time, there can be more elements added to get a more precise estimation.

M

Chapter 9

Results

In this chapter, there will be a overview of results of the performed measurement.

- **Confidential** -

9.1 HKW - Measurement 1: Confidential - Confidential

- **Confidential** -

9.2 HKW - Measurement 2: Confidential - Confidential

- **Confidential** -

9.3 HKW - Measurement 3: Confidential - Confidential

- **Confidential** -

9.4 Conclusion

Table 9.1: Overview Freight Scores

Reference Number	**confidential**	**confidential**	**confidential**
Freight Score	**confidential**	**confidential**	**confidential**

Throughput

confidential

Table 9.2: Throughput

confidential	**confidential**	**confidential**	**confidential**
confidential	**confidential**	**confidential**	**confidential**
confidential	**confidential**	**confidential**	**confidential**
confidential **confidential**	**confidential**	**confidential**	**confidential**
confidential **confidential**	**confidential**	**confidential**	**confidential**

Contamination

confidential

Table 9.3: Overview of Contamination Score

Reference Number	**confidential**	**confidential**	**confidential**
Freshness	**confidential**	**confidential**	**confidential**
Contamination	**confidential**	**confidential**	**confidential**
Sand	**confidential**	**confidential**	**confidential**
confidential	**confidential**	**confidential**	**confidential**
Moisture	**confidential**	**confidential**	**confidential**
Input/Output	**confidential** %	**confidential**%	**confidential** %

Final

Material with a high expected throughput, that is heavy and though has a high throughput speed, which has a high added value. These 3 elements have a high impact on the cost price.
The Added Value is also influenced by the kg of output in ratio to the kg of resource input. For example the PP mono Shred has a relatively low ratio. The throughput speed is high compared to cups, but has a lower ratio. This makes that the PP mono Shred, in combination with a high purchasing price, has a low Freight Score. A good throughput and a good ratio results in a good Freight Score for the Caps.

Chapter 10

Discussion and Recommendations

In this part we will discuss shortcomings, the relevance and recommendations for this research.

10.1 Discussion

In order to determine the statistically robustness, more testing on the following parts have to be done:

1. Tests have to be done with different sample sizes. For example one bale, one freight or multiple freights. Currently it has a financial and operational reasoning behind that is mentioned earlier.
2. The production process can behave differently, when it is past the warm-up period and running at a normal capacity. Because it is a continuous flow process.
3. **Side Note:** Due to the fact that you're dealing with waste, it will be very difficult to have a completely statistically robust measurement plan. Within Rodepa there is a saying: "Every freight of waste is unique and will never come back." There can be deviation among freight that are characterised the same.
4. The sludge production is currently not known and considered. Data on the throughput time has to be gathered in order to draw substantiate conclusions on the sludge production.

10.1.1 Threat to Validity

Change Production Line

The score is based on a specific washing line. When the washing line changes, the results will change. This could mean that the previous score become useless. This depend on the adjustment to the washing line.
They recently installed for example a new shredder, which give a much better throughput

rate. And as mentioned earlier in Chapter 9 - Conclusion this also has a big effect on the Freight Score.

Increase in Skill Operators

The workers are getting more skilled over the course of time. This could mean that the throughput increases, while the resource input remain ver similar. This means the results could vary.

10.1.2 Added Value

Quality of Plastic Waste for Washing Street

The washing lines vary between recycling companies. Thus it is not possible to determine one quality standard that can be used for all washing lines.
A washing line can be specialised to wash of organic contamination such that the regrind can be considered a good quality for in the extrusion process, while other lines struggles to produce a good quality. The same can be said for big chunks of metal, due to a technical innovation.
This can be said for all types of contamination. Every washing line has a different quality standard for the resource input, that can change due to technical innovations.

Added Value of Regrind

In order to get a better understand of the selling price of the regrind, you need to gather samples of regrind that are available on the market. This data can be compared to the end product of the washing line, so that the added value can be calculated more precisely. As mentioned earlier, it is possible to do a quality checks on regrind.

Demand & Supply

The added value also depend on demand and supply. The plastic market is a very active market that is constantly changing. For example the changing European and national regulations in plastic. The market is also under the influence of seasonality, certain streams deviate in availability throughout the year. The value added to a product is very dependent on the state of the market. The sellings price can change, while the production line stays the same.

10.2 Relevance

In this section the relevance of this project will be discussed.

10.2.1 Scientific Relevance of this Research

I want to establish a relation between the Incoming Freight Report and the Freight Score. A different score can be hanged to a waste freight, with the help of a weighing scale of the different categories. This can only be done if sufficient data has been gathered. On the basis of the gathered data, they can make a strategic decision on which waste freight they can add the most value to.
The relevance and the useability of this research, especially the Incoming Freight Report, will become clear over the course of the data gathering process.

10.2.2 Company Relevance of this Research

The goal of this research is to provide Rodepa with a tool to measure the true costs of production. This will give them more insight in the margins per processed input.
The Incoming Freight Report can be used to make better strategic and substantiated decision on which resource input to purchase.

10.2.3 Trust Between Supplier and Recycler

In the plastic recycling you're very dependent on your suppliers.

1. First off, you're depended for the quality of the waste. Recycling is just like cooking, a process of mixing ingredients until you have a certain product. In plastic recycling you mix bad quality and good quality plastic in an extruder together in order to get a homogene quality that is just right for a customer. If you cannot reach that quality, because one of your inputs is not to specification, thus not useable, you cannot deliver to your customer.

2. Second off, you're dependent on your supplier for the usability of the product. If a If there is a contamination that it could cause the production to come to a hold. Then it will increase the difficulty to make the product profitable.

If you cannot rely on your suppliers to deliver the right input systematically, then you cannot systematically deliver your customers. This turns recyclers into a less reliable supplier, which makes them a less attractive partner to do business with. A problem that has an effect on the profitability and the viability of the plastic recycling industry.

Trust between suppliers and waste processors or recyclers is very important.

10.3 Sustainability Analysis

During my time at Rodepa, I was introduced to a scientist that did research on the sustainability of recycled plastic.

The following subjects where of interest to him:

1. Is there a difference between foil and hard plastics?
2. Is there a difference between PP and HD-PE?
3. What is the difference between a bad quality and good quality? This is what I'm hoping to define with my Incoming Freight Report for the company. And also predict the effect of a freight on the whole production process.

It is done according to a sustainability analysis. In this model the washing process and the extrusion process was considered. Both production process are described as a simplified model of inputs and outputs.
These inputs of the washing line are considered in this research:

1. **Water Consumption: Closed Loop water consumption is part of Source Water**
   The closed loop water and the source water are used in the washing process. These both streams are considered in this research as one, under the name: source water. Closed loop water is the internally cleaned water and source water is coming straight from the source.
   More research has to be done on the closed In order to perform a sustainability report.
2. **Electricity consumption**
   This is considered in this research.
3. **Additive Consumption**
   The additives are used to wash the product and clean the water used in the washing process. And there are also additive used to clean the source water that is used in all the production lines. There is also a water cleaning system, that cleans the water before it goes in the sewage. On the last 2 parts, more research has to be conducted in order to understand this.

   (a) **Source Water:** The additives used to clean the source water and closed loop water are not considered in this research. This due to the complexity of the water cleaning system. There is one source, that feed closed loop and source water to the extruders and the washing lines. There is currently no adequate equipment installed to measure the water consumption of the individual processes.

   (b) **Sewage Water:** Next to that there is also hard to measure and estimate the amount of water that is delivered to the sewage. Before the water goes into the sewage, the water is also cleaned with additives. This consumption can be measured but is hard to link back to the output of a washing line or extruder line.
   For the contaminated water, you also pay a fee to the Water Authority. You pay a fee for every "vervuilingseenheid" in Dutch, or contamination unit. This is currently estimated.

10.4 Recommendations

The following points have to be addressed in order to do a full sustainability analysis.

1. **Source and Closed Loop Water (or Cleaned Water)**
   As mentioned earlier, there has to be done more research in order to measure this. Because you're dealing with seasonality, it is hard to get a good estimation of the source water that is used. This is the water that is pumped from a internal well and cleaned by the internal water cleaning system. The costs for 1 liter of source water could be different in the summer and in the winter.

2. **Extrusion Process**
   A similar measurement plan can be made for the extruder. This requires additional research. But the Measurement Plan can be a good basis in order to do this.

10.4.1 Costs Analysis

A more elaborate costs analysis can be made. This is currently not considered in the costs analysis: Maintenance Overhead Related to the washing line, Budgeted Overhead, the costs of source water and closed loop water.
This can't be done currently done, due to the fact that the current accounting program and the current way they do they do invoicing is not suitable.
The invoices, of both the labour and the parts, related to the maintenance of the production lines, are currently not linked to the specific production lines. They are booked under overhead. This makes it hard to find out the total maintenance costs of the production line.

10.4.2 Execution of Measurement Plan on Partial Freights

During the measurement on partial freights it was noticeable, that the results were as accurate as full freights. This can also be considered to be a threat to validity.
This is has the following reasons:

1. During washing process, the water will be contaminated by the process freight in a varying degree. This can mean that the water will be cleaned and new water and additives will be inserted in the process, after a freight has been processed and all data has been collected.
   This is also true for full freights, but this effect is less than with partial freights.

2. The fraction of shredder downtime of the total production time can be different with partial freights, due to the fact that the time it takes to transition form one freight to another is often similar.

So an advice will be to do only measurements on full freights measurement.

10.4.3 Time Series Analysis

A Time Series Analysis could be of use, if you want to better understand the behaviour of the production line. It increases the complexity of the measurement plan. In order to do a time series analysis, the following has to be adjusted:

1. The times registration has to be different. The times that are written down on the production sheets are e.g. big bags. And this is the time that a big bag is weighed. Due to the extra complexity and the required alertness, could make the data inaccurate.

2. The electricity measurement provides very useful and reliable data, about the up and down time of the production line. Keep in mind that the shredder shuts off, when the engines of the grinding mill reaches an ampere of 160. This is currently not taken into account and not measured in the electricity measurement and the calculation of the production time of the AUPT.

3. The production line itself is generation a lot of data. This data can be extracted, when in the possession of the right equipment. The data can be used to monitor the health of the machines, predict maintenance and learn more about the process. It can also be used to further support the time series analysis and make the data more robust and reliable.

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Appendix A

Overview of Production Lines

A.1 Overview of all Inputs and Output incl. pictures

- confidential -

A.2 Overview of Production Lines incl. Locations of Inputs

Overview of Production Line HKW

- Confidential -

Overview of Washing Lines with Inputs

- Confidential -

Overview of Production Line FWL

- Confidential -

Figure A.1: Overview of Washing Lines with Inputs

Appendix B

Problem Cluster

1. Company is missing an instrument/plan to measure the data needed to measure the performance: The company cannot measure e.g. up/-down time and other production related information, input and output usage. They can measure the total consumption and production of the company, but not specific to a production line.

2. Relevant data is missing: Relevant data from which you can derive up/-downtime and other production related information is missing. And the data from which you can derive the total consumption and production of a production is missing.

3. Quality Resource Input is unknown: there is no handle or protocol on which you can determine the quality of a resource input. The company cannot predict and will not be able to predict the effect of certain characteristics of a resource input on the production process.

4. Purchasing decision of a Resource input based on price: But a load of resource input can be refused on the basis of certain characteristics. For example there is to many foils in the load or the load contains too much PE, because this can disturb the process.

5. Quality of the resource input has influence on the production process: There are many factors of a resource input that can influence the production performance and input usage. For example if there is a lot of contamination in the resource load, then we have use much more water to get a clean end product. And a lot of contamination clogs the filters faster, so that you have much more filter changes, which are very time consuming and

6. Deviation in production input usage e.g. Water usage, electricity usage

7. Deviation in production performance e.g. Deviation in maintenances: Depending on a resource input and the quality of it, you can have deviations in production performance due to filter changes. For example, I have heard that they have had to change filter every 4 hours and have had to change filter after 2 weeks.

8. Information about the performance of a product is not coupled back to purchasing department: The purchasing gets feedback on the resource input when it is being

refused and get feedback when the load of a good quality. This is done subjectively. But they don't get feedback on the performance of their resource on the production line.

Appendix C

Literature Study

Appendix I: Literature Study

Webster & Watson (2002) described the following 4-steps to do a systematic literature review:

The research question that will be answered is:

What KPIs are relevant to the performance of a production line?

1. Define the keywords, search strings, and inclusion & exclusion criteria to search in scientific databases such as Scopus and Web of Science. The following was used to find relevant articles:

a. Search String: Production Process AND KPI, Dashboard and KPI

	Production line/process	KPI	Dashboard	Manufacturing	Search String
Search 1	x	x			"Production process" AND KPI
Search 2		x	x		"KPI" AND "Dashboard"
Search 3		x		x	"KPI" AND "Manufacturing"

b. Date Range: 1990 - Present. Dashboards weren't used until 1990.

c. Inclusion and Exclusion criteria:

Nr	In- or Exclusion Criteria	Reason
1	Include: all articles from 1990 - present	Dashboards weren't available before that time
2	Exclude: Journals:Computer Science, Materials Science, Chemical Engineering, Mathematics, Computer Science	Is not the industry to which this is relevant
3	Exclude: Non-Dutch and Non-English Articles	Hard to read

Search results

Search Protocol for Scopus	Scope	Date of search	Date range	Number of entries
KPI AND production line	Title, Keywords and Abstract	23-4-2019	1990-present	45
KPI AND Dashboard	Title, Keywords and Abstract	23-4-2020	1990-present	86
Manufacturing AND KPI	Title, Keywords and Abstract	24-4-2020	1990-present	312
Total Endnote				443
Selecting based on inclusion/exclusion criteria				433

Selecting based on availability				72
Removing duplicates				45
Total Read				24
Included after complete reading				6

Literature list of articles found in literature review

Nr	Journal	Authors	Title	Citations	Publisher
1	International Journal of Production Research	A. Mousavi, H.R.A. Siervo	A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	219	Taylor & Francis
2	Performance metrics for Intelligent Systems (PerMIS) Workshop	J. Arinez, S.Biller	Benchmarking Production System, Process Energy, and Facility Energy Performance using a system approach	24	PerMIS
3		Li Zhu, Charlotta Johnsson, Jaco Mejbik, Martina Varisco, Massimiliano Schiraldi	Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard	14	IEEM
4	IEEE Internal Conference on Industrial Engineering and Engineering Management	Li Zhu, Charlotta Johnsson, Jaco Mejbik, Martina Varisco, Massimiliano Schiraldi	Key Performance Indicators for Manufacturing Operations Management in the Process Industry	12	IEEM
5	The 7th International Conference on Applied Energy	Carl-Fredrik Lindberg, SieTing Tan, JinYue Yan, Fredrik Starfelt	Key performance indicators improve industrial performance	56	Elsevier
6	IEEE Industrial Cyber-Physical Systems	Muhammad, U.; Ferrer, B.R.; Mohammed, W.M.;Lastra, J.L.M.	Implementing and Visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	21	Machines

Short summary of article listed above. Numbers correspond to the articles in the list.

Nr	Summary
1	This paper gives a good overview of a lot of possible KPIs. A good overview of the different categories of KPIs, and also a lot of the mutual relationships and dependencies between KPIs. There are also a lot of formulas on how to calculate the KPIs.
2	This paper gives an handle to make a conceptual design of the manufacturing system. It gives the basic requirements that are needed to make a conceptual design analysis: 1. Process flow, 2. production statistics, 3. resource - equipment list,4. energy resources. It also gives a good handle to look at how energy consumption data can be used to find the state (idle/busy/down) of the production equipment. This can be used to determine

	down and up time and effectiveness of the equipment. But we don't want to make a simulation model, but it give s a good insight in how you might do data collection.
3	This paper is similar to KPI for manufacturing operations management in the process industry. It claims that there is a gap between ISO 22400 and the process industrial needs. It has 3 main gaps: 1. Only few of defined KPIs are suitable for the process industry, 2. relationships and working conditions of each unit are different, 3. Some defined KPIs cannot be computed or even meaningless. It proposes some alterations, or removals of certain KPIs. It proposes a different method to calculate Utilisation, setup and Allocation.
4	This focuses on process industry with continuous processes, instead of the discrete industry. It comes up with a novel framework for organizing KPIs and associated measurement elements. KPIs can organised in 3 parts, the equipment KPIs and the process KPIs and the measurement elements.
5	This paper gives an alternative to benchmarking results. The first thing to do is to identify the process signals that are strongest correlated with the KPI and then change these process signals in the directions that improves the KPI. It suggest to identify waste in different forms, and reduces that waste to improve performance. It also proposes a method on identifying process signals or combinations of process signals that are strongly correlated with the KPI of interest.
6	Give a short summary of the whole process for implementing KPIs and many background information. It contains information about current KPIs. A description of an approach with technical details and conceptual details. Also a case is discussed in which they implement the KPIs with the dashboard. They give a overview of the result of the implementation with the used KPIs.

The concepts that are derived from the theory are listed below. The use and the integration of these theories are also listed below.

Nr	Integration of Theory
1	I'll be looking at possible relations Between KPIs in my research. Also use these formulas to calculate KPIs
2	It will help with the description of the production line and give an insight in how we might measure energy consumption.
3	Discussed KPIs will be further looked at and possibly used
4	Framework for integrating KPIs will be used to get a good overview of the used KPIs and their calculation. There are also useful KPIs that can be useful for my research
5	Process signals will be definitely used to get insight in the state of the production process in order to get .
6	I will use approach to give me an idea on how to structure my implementation process.

Nr	Concepts	
1	Interdependencies, relationships	Certain KPIs are dependent on each other. For example they have parameters in common to calculate the KPIs.

2	Process flow	A description of the flow of the resource throughout the production process.
	production statistics	Parameters relating to production that are needed to calculate the KPIs
	resource- equipment list	Inventory of all the resources that are used as input, and an inventory of all the equipment or machines in the production process.
3	Process industry	Industrie where the production process occurs in batch of materials that is indistinguishable.
3	Discrete industry	Industry where the production is made of distinct items.
4	Production Modality	The characteristic of the output of a production process, e.g. Continuous flow or a discrete entity
	Production form	The shape of the production, for example fluid-based or Pieces and parts
	Work unit	How the process is organised, e.g. unit, work cell
5	Process Signals	Parameters that are needed to calculate the KPIs, that are relevant to the production process.
	Energy KPIs	The energy could be in different forms for example electricity, gas, coal, oil, biomass, steam, etc. The produced output could e.g. be in units of tons/h, m3 /h, units/h, etc.
	Raw Material KPIs	Raw-materials may not only be the main raw-material for a plant, it could also be water, chemicals, etc.
	Operation KPIs	The main Operation KPI is the Overall Equipment Effectiveness (OEE) [15] and its individual parts
	Control performance KPIs	Control performance may influence product quality, production speed, equipment wear, etc.
	Maintenance KPIs	Too little maintenance causes an excessive number of unplanned stops resulting in lost production and emergency maintenance. Too much maintenance causes large maintenance costs and lost production during each planned maintenance.
	Equipment KPIs	Equipment KPIs These KPIs can be used to follow the condition of equipment and in some cases also predict when maintenance will be required.
6	KPI description	See table below
	Effect model diagram	

Table 1: Structure of KPI description according to ISO 22400.

	KPI Description
Content	
Name	Name of the KPI

ID	A user defined unique identification of the KPI in the user environment
Description	A brief description of the KPI
Scope	Identification of the element that the KPI is relevant for, which can be a work unit, work center or production order, product or personnel
Formula	The mathematical formula of the KPI specified in terms of elements
Unit of measure	The basic unit or dimension in which the KPI is expressed
Range	Specifies the upper and lower logical limits of the KPI
Trend	Is the information about the improvement direction, higher is better or lower is better
Context	
Timing	A KPI can be calculated either in real-time: after each new data acquisition event on demand: after a specific data selection request periodically: done at a certain interval, e.g., once per day
Audience	Audience is the user group typically using this KPI. The user groups used in this part of ISO 22400 are Operators: personnel responsible for the direct operation of the equipment Supervisors: personnel responsible for directing the activities of the operators Management: personnel responsible for the overall execution of production
Production methodology	Specifies the production methodology that the KPI is generally applicable for Discrete Batch Continuous
Effect model diagram	The effect model diagram is a graphical representation of the dependencies of the KPI elements that can be used to drill down and understand the source of the element values NOTE This is a quick analysis which supports rapid efficiency improvement by corrective actions, and thus reduces errors
Notes	Can contain additional information related to the KPI. Typical examples are Constraints Usage

	Other information

Appendix J: Theoretical Framework

Process Industry Framework

A framework is used from **Key Performance indicators for manufacturing operations management in the process industry** (Li Zhu, 2017). It will help with the structuring of the KPIs and the associated measurement elements. The production company that I conduct my research at is a processing company.

Measurement elements

Basic measurements, called measurement elements have to be collected in order to calculate KPIs. According to ISO 22400 Part 2, these elements - i.e. the "relevant measurements for use in the formula of a key performance indicator" - can be divided into three main categories; time, quality and logistical. The logistical elements contain both quantity and inventory measurements. In this project, the focus will be on the two categories time and quantity measurement elements.

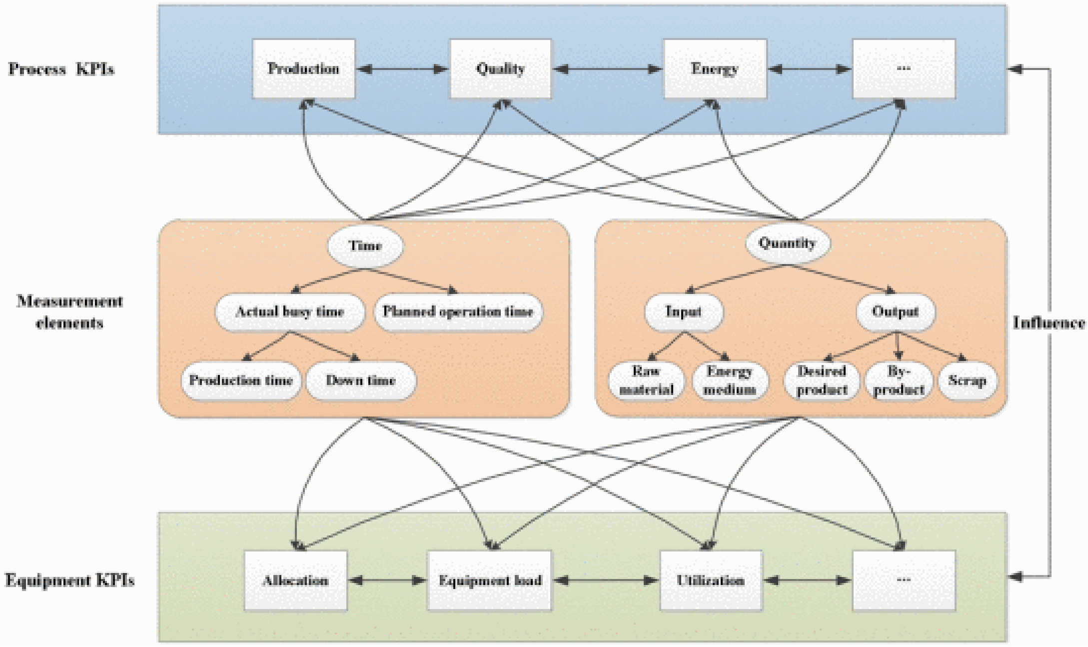
The **time** measurement elements are comprised of data related to the duration of the production process.The time measurement elements are comprised of data related to the duration of the production process, including planned operation time and actual operation time. Moreover, the actual operation time can be divided into production time and downtime to increase the level of detail. The time elements are similar to the definitions in ISO 22400.

Something to consider is that in the process industry, according to this paper, it is likely that the product or the **quantity** of the product being processed in a certain production unit is difficult to measure, and often only become available in the logistical measurement elements. This can for example be measuring the weight of a processed load by subtracting the weight of a loaded truck and the weight of the unloaded truck. And also the weight of the end product in the loaded big bags, because they are weight by the forklift operators.

Equipment KPIs and Process KPIs

KPIs for the process industry can be analyzed from 2 levels: process KPIs and equipment KPIs. The performance of the production equipment is directly influenced by the performance of the production equipment.

Process KPIs can be divided into three categories: production, quality and energy KPIs. The equipment KPIs include allocation ratio, utilization efficiency and equipment load ratio. See figure 1 for a schematic



overview.

Figure 1: Framework of KPIs

Integration of theory

This theory will help with determining the efficiency of a production line of a process industry, so that I can have a better and more relevant approach to my project. The company at which I do my research is a processing company. I can calculate KPIs better, because they are better applicable to my project.

Theoretical Framework with KPIs that can be considered.

In figure 1 there is a framework lay-out. Below you can find the different elements, process KPIs, measurement elements and equipment KPIs put into a scheme. KPIs from other articles are also listed here. The KPIs that will be used in my project are yet to be determined.

1. Process KPIs

Perspective source		**Process KPIs**	
	Production	**Quality**	**Energy**
Key performance indicators for manufacturing operations management in the process industry	Throughput rate	Quality ratio	Energy Consumption
	Technical efficiency	Actual to planned scrap ratio	
		Scrap ratio	
		Finished goods ratio	
Key performance indicators for manufacturing operations	Availability	Actual to scrap ratio	Comprehensive energy consumption

management – gap analysis between process industrial needs and ISO 22400 standard			
	First pass yield	production loss ratio	
	Critical process capability index	rework ratio	
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	process capability index	scrap ratio	
		Other loss ratio	
		Finished goods ratio	
		Integrated goods ratio	
		Throughput rate	
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	Availability	Actual to planned scrap ratio	
	Allocative efficiency	Scrap ratio	
	Technical efficiency	Rework ratio	
	Utilization efficiency	Fall of ratio	
	Effectiveness	First time quality	
	Allocation ratio	Quality buy ratio	
	Production process ratio		
	Throughput rate		
	Setup ratio		
	Line throughput rate		
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach	Resource and production data (needed)	Resource and production data (needed)	Resource data (needed)
Key Performance Indicators Improve Industrial Performance	Percentage Scheduled operation time	Percentage of full quality product	Energy input / Produced output
	Percentage actual uptime	Raw-material input / Produced output	
		Emission / Produced output	

		Waste deposit / Produced output	
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems		Scrap Ratio	
		Quality Ratio	

2. Measurement elements

Perspective source	Measurement elements	
	Time	**Quantity**
Key performance indicators for manufacturing operations management in the process industry	Planned Operation Time	Input Quantity
	Actual busy time	Raw Material Quantity
	Actual downtime	Energy medium quantity
	Actual production time	Output quantity
		Desired quantity
		By-product quantity
		Scrap quantity
Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard		Comprehensive energy consumption
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	Actual unit delay time	Good part
	Actual order execution time	Good quantity
	Planned run time per item	Equipment production capacity
	Actual unit busy time	Actual production
	Actual unit processing time	Rework quantity
	Actual unit setup time	Scrap quantity
	Planned busy time	Integrated good quantity
	Preventive maintenance time	Inspected part
	Operating time between failures	Machine capability index
	Time to failure	Other loss

	Time to repair	Production loss
	Corrective maintenance time	Failure event
		Lower specification limit
		upper specification limit
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	Actual unit processing time	Good quantity
	Àctual production time	Scrap Quantity
	Actual unit setup time	PLanned scrap quantity
	Actual unit down time	produced quantity in the first operation process
	Actual unit idle time	
	Actual unit busy time	
	Actual order execution time	
	Actual transportation time	
	Time to failure	
	Operating time between failures	
	Time to repair	
	Failure event	
	Corrective maintenance time	
	Preventive maintenance time	
	Blocking time	
	Starving time	
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach	Process cycle times	Conveyor speeds
	Process setup times	Resource/process energy consumption
	Resource mean time between failure	Process scrap percentage
	Resource mean time to repair	

Key Performance Indicators Improve Industrial Performance	Operating Hours	E.G. heat transfer rate of heat exchanger
	Operating speed	E.g. Number of valve openings
	load	E.g. Vibration amplitude
	Startup	
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	Actual unit busy time	Scrap quantity
	Actual production time	Good quantity
	Planned busy time	Produced quantity

3.. Equipment KPIs

Perspective source		Equipment KPIs		
	Allocation	**Equipment Load**	**Utilisation**	Maintenance 1*
Key performance indicators for manufacturing operations management in the process industry	Allocation ratio	Equipment load ratio	Utilization efficiency	
Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard	Technical efficiency	Machine capability index	Setup ratio	Mean operating time between failures
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	Effectiveness	equipment load ratio	Utilization efficiency	mean time to repair
	Production process ratio	Critical machine capability index		Corrective maintenance ratio
		net equipment effectiveness index		
		Overall equipment effectiveness index		
		Fall of ratio		
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems		Buffer capacity	Blockage ratio	Mean time to failure

			Starvation ratio	Mean time to repair
			Work in process	
			Overall Equipment effectiveness	Mean delay time
			Net equipment effectiveness	Corrective maintenance ratio
			Mean setup time	
			Mean operating time between failures	
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach				
Key Performance Indicators Improve Industrial Performance		Percentage production rate of max rate	OEE	Maintenance costs / Produced output over a time period.
				Maintenance time / Produced output over a time period.
				Number of alarms over a time period
				Equipment ware
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	Allocation Efficiency		Utilization efficiency	
	Availability			

1* Added by theory from: A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems

Appendix D

Quality Control Tests

D.1 Overview of all Quality Control Tests

- Confidential -

D.2 Process Flow Quality Checks

- Confidential -
    - Confidential -
    - Confidential -

Figure D.1: Part 1 of the Quality Check

Figure D.2: Part 2 of the Quality Check

Figure D.3: Part 3 of the Quality Check

Appendix E

KPIs

E.1 Tailor Made Production KPIs HKW and FWL

List of Input Quantities

Below you find a list of the inputs that the washing lines consumes. We are considering all elements of the blackbox as mentioned in the production line description, together with the elements of the measurement plan. The input are all the input that are needed in order to get a useable output.
Short overview of the Quantity Measurement Elements related to the input.

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Quantity	Input Quantity Electricity
2	Measurement Element	Quantity	Input Quantity Resource
3	Measurement Element	Quantity	Input Quantity Additive
4	Measurement Element	Quantity	Input Quantity Source Water
5	Measurement Element	Quantity	Input Quantity Vitens Water

Name: Input Quantity Electricity - Measurement Element - Quantity

Description: The amount of additives that is used during the washing process.
Scope: HKW or FWL
Formula: End Standing Electricity Meter - Begin Standing Electricity Meter
Unit of Measure: kWh
Range: NVT
Trend: The higher the kWh, the more kWh is produced during the production process.

Name: Input Quantity Resource - Measurement Element - Quantity

Description: The input for the washing lines that will be processed, depending on the type of freight it is delivered as bulk or in bales.
Scope: The truck with freight.
Formula: Begin Weight Loaded Truck - End Weight Unloaded Truck
Unit of Measure: Kilo grams
Range: NVT
Trend: The higher the Kg, the more product is extracted form the waste.

Name: Input Quantity Additives - Measurement Element - Quantity

Description:The amount of additives that is used during the washing process.
Scope: HKW or FWL
Formula: End Weight VARIBOX or IBC - Begin Weight VARIBOX or IBC
Unit of Measure: Kg(can be calculated to Liter)
Range: NVT
Trend: The higher the weight, the more additives are used.

Name: Input Quantity Source Water - Measurement Element - Quantity

Description:The amount of source water that is being used in the process. This water also consist of circulated water and water from the source itself.
Scope: HKW or FWL

Formula: End Level Water Meter Source - Begin Level Water Meter Source
Unit of Measure: Liter
Range: NVT
Trend: The higher the quantity, the more water is used.

Name: Input Quantity Vitens Water - Measurement Element - Quantity

Description:The amount of Vitens water that is being used in the process.
Scope: HKW or FWL
Formula: End Level Water Meter Source - Begin Level Water Meter Source
Unit of Measure: Liter
Range: NVT
Trend: The higher the quantity, the more water is used.

List of Output Quantity

Below you find a list of the output that the washing lines produce. This includes the useable product quantity, by-product quantity and waste quantity.
Short overview of the Quantity Measurement Elements related to the output.

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Quantity	Product Output Quantity
2	Measurement Element	Quantity	Foil Output Quantity
3	Measurement Element	Quantity	Waste Output Quantity
4	Measurement Element	Quantity	Slik Output Quantity
5	Measurement Element	Quantity	Angle Share Quantity

Name: Product Output Quantity - Measurement Element - Quantity

Description: The amount of end product that is produced by the washing line, after the input has been processed. Depending on the washing line, it can be grinded plastic of the HKW or plastic chips.
Scope: HKW or FWL
Formula: HKW: Total Weight of the Output Big Bags. FWL: Total Weight of the Output Big Bags after removing them from the Silo
Unit of Measure: Kilograms
Range: NVT
Trend: The higher the quantity, the more output is produced.

Name: Foil Output Quantity - For HKW only - Measurement Element - Quantity

Description: The amount of foil product that is produced by the HKW, after the input has been processed and separated from the end product. Depending on the quality of the Foil output it is considered waste or a product. This depends on the amount of paper between the foil.
Scope: HKW or FWL
Formula: Total Weight of the Output Big Bags.
Unit of Measure: Kilograms
Range: NVT

Trend: The higher the quantity, the more foil is separated.

Name: Waste Output Quantity - Measurement Element - Quantity

Description: The amount of waste that is produced during the washing process and extracted from the input. The definition of waste is all the output of the washing line that the company itself cannot turn into an end product.
Scope: HKW or FWL
Formula: Total Weight of the full Waste Bins - Total Weight of the empty Waste Bins
Unit of Measure: Kilograms
Range: NVT
Trend: The higher the quantity, the more waste is produced.

Name: Angle Share Quantity (or missing weight) - Measurement Element - Quantity

Description: The amount of missing weight, so the difference between input and outputs.
Scope: HKW or FWL
Formula: Resource Input Quantity - Waste Output Quantity - Product Output Quantity - Foil Output Quantity (if used: Slik Output Quantity)
Unit of Measure: Kilograms
Range: NVT
Trend: The higher the quantity, the more waste is produced.

Currently Not Considered: Name: Slik Output Quantity - Measurement Element - Quantity

Description: An output that is currently not considered is the silk production. This is due to a technical difficulty. The dewatering screw that produces the silk output is from both the HKW and the FWL. So there is no method to estimate the silk production of a production batch. The throughput time of the slik is also unknown within the company.
This is definitely an output to consider in the future, due to its high potential energy.
The amount of end product that is produced by the washing line, after the input has been processed. Depending on the washing line, it can be grinded plastic of the HKW or plastic chips.
Scope: HKW or FWL
Formula: Total Weight of the full Slik Bins - Total Weight of the empty Slik Bins
Unit of Measure: Kilograms
Range: NVT
Trend: The higher the quantity, the more slik is produced.

Resource Input Quantity			
Product Output Quantity	Waste Output Quantity	Foil Output Quantity	Missing Weight = Angle Share Quantity

Table 9: Graphical representation of Input - Output Calculation

Additional KPI: Maintenance

List of Failure Event - Measurement Elements

Upon dealing with plastic waste, there is a change that the process come to a hold due a fatal pieces of contamination coming into the production line. The contaminants that could cause the process to come to a hold is described in the part KPIs of the input. The production process could also come to a hold due to technical difficulties. For example a water tube that breaks or a bearing that is worn out.
In order to properly establish the quality of the resource input, you have to separately consider the failures that are caused by the input and other failures. This way you can say partially something about the quality of input from a supplier. The distinction will be discussed further below.

Failure Event Occurrence - Measurement Element - Quantity

Description: The amount of failures events that occur during the production process. There is a distinction between a failure event caused due to technical difficulties and a failure event caused due to the input.
This distinction is also used in with the KPIs:

- Name: Failure Event Occurrence Production Related

  Description: Mentioned earlier. For example: a water tube that is broken or the forklift is broken.
  Scope: HKW or FWL
  Formula: The frequency that a production line is down due to technical failures.
  Unit of Measure: Integer
  Range: NVT
  Trend: The higher the frequency, the more often the production line is interrupted.

- Name: Failure Event Occurrence Input Related

  Description: Mentioned earlier. Example: a piece of metal that causes the shredder to come to a halt.
  Scope: HKW or FWL
  Formula: The frequency that a production line is down due to input related failures.
  Unit of Measure: Integer
  Range: NVT
  Trend: The higher the frequency, the more often the production line is interrupted.

Name: Failure Event Time - Measurement Element - Time

The amount of time that the production process is down due to a failure event.
The starting time is the moment that the process comes to a hold due to a failure event.
The end time is the moment that the failure is fixed and the process is starting back up.
Again a distinction between the 2 types of failures is made.

- Failure Event Time Production Related
  Description: Mentioned earlier.
  Scope: HKW or FWL
  Formula: As mentioned above: Start Time Production Failure Event - End Time Production Failure Event
  Unit of Measure: Hours:Minutes
  Range: NVT
  Trend: More time means that the production line is down.
- Failure Event Time Input Related
  Description: Mentioned earlier.
  Scope: HKW or FWL

Formula: As mentioned above: Start Time Input Failure Event - End Time Input Failure
Event
Unit of Measure: Hours:Minutes
Range: NVT
Trend: More time means that the production line is down.

Failure Event Type

There are different events that could the process to come to a standstill. The events can be categorised, due to the frequent occurrence. Again the failure events are divided into 2 categories.

Failure Events due to failure of Production Line.

Every machine in the production line has a change to break down and cause the production line to come to a hold. This is often due to general usage of the machine and wear and tear. The failure event can be described as followed:

1. **Machine Number**
    1. The machine number of a machine in the production line can be found in the Appendix
2. **Failure Event : Machine Related Failures**
    1. Periodic Maintenance Failure: e.g. Worn Out Gearing, Broken Gearing
    2. Preventive Maintenance Failure: e.g. Full Screen, Cutter Blades Worn out
    3. Electrical Issue: e.g. blown fuse, broken frequency controller, broken cable.
    4. Non Maintenance Related Failure: e.g. Broken Water Tube,

Non Machine Related Failures

5. Employee Related Failure: e.g. Breaking a piece of equipment by an employee.
6. Equipment Related Failure: e.g. Breaking Down of a forklift.

Example: The friction washer of the HKW has a broken gearing → 2.40 - 1

Failure Events due to Input

As mentioned in KPI for Input, you are dealing with contamination in the waste that can cause the process to come to a halt. The following could be the cause of that.

1. Metal:

a. E.g. pieces of metal that breaks the shredder blades

1. Small Sand Particles:

a. E.g. Sand in the circulating water tank of the FWL. This is due to the fact that there is too much sand in the input material that the filters couldn’t filter it out of waste water.

1. Big Sand Particles:

a. E.g. Stones or piece of concrete that breaks the shredder blades.

1. **For FWL only:** Stretch Foil

a. Foil that wraps around a transportation screw s.t. the process comes to a halt.
b. If this happens, write down the number of the machine as described in the Appendix Production Line Description .

List of Production Related Time

All the measurement related to the production process of the HKW and FWL. These elements help with the calculation of the KPIs.

Short overview of the Time Measurement Elements related to the production.

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Time First Bale Thrown In
2	Measurement Element	Time	Time First Output Comes Out
3	Measurement Element	Time	Starting Time Production
4	Measurement Element	Time	Ending Time Production

Name: Time First Bale Thrown In - Measurement Element - Time

Description: The first time a bale is thrown in the machine.
Scope: HKW or FWL
Formula: Time First Bale Is Thrown In
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Time First Output Comes Out - Measurement Element - Time

Description: The first time the output of the production line spikes. This time is hard to establish because it is a continuous flow process. Even if the production line has just started, it will produce a small amount of output left from the previous freight.
Scope: HKW or FWL
Formula: Time First Bale Is Thrown In
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Starting Time Production - Measurement Element - Time

Description: The time the production start. This is when the shredder is turned on for the first time. The HKW has a warm up period of around 15 minutes separate from the shredder. The FWL has a warm up period of around XX separate from the shredder.
Scope: HKW or FWL
Formula: Time Shredder Has A First Peak in Amperes
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Ending Time Production - Measurement Element - Time

Description: The time the production end. This is when the shredder is turned off. The HKW has a warm up period of around 15 minutes separate from the shredder. The FWL has a warm up period of around separate from the shredder. Or when the last big bag is tapped off. This depends on the freight that is processed next.
If they freight of the next freight that will be processed, requires the same settings of the washing line as the preview freight. Then there is no adjustment of the machines needed and can the shredder remain running. This is to ensure that the production line can maintain a high uptime, while performing a measurement.
Scope: HKW or FWL
Formula: The last time a shredder turns on. Time last big bags is tapped off.
Unit of Measure: Hours:Minutes
Range: Time

Trend: NVT

Production Time Shredder

Below you find a list of elements in which you characterise the shredder times. It refers to the time that a shredder is busy.

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Starting Time Production
2	Measurement Element	Time	Ending Time Production
3	Measurement Element	Time	Up Time Shredder
4	Measurement Element	Time	Down Time Shredder
5	Measurement Element	Time	Starving Time Shredder
6	Measurement Element	Time	Busy Time Shredder

Name: Up Time Shredder- Measurement Element - Time

Description: The time the shredder is up. This can be found In the electricity measurement, when the shredder is registering an Ampere higher than 0.
Scope: HKW or FWL
Formula: Up Time Shredder
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Down Time Shredder- Measurement Element - Time

Description: The time the shredder is down. This can be found In the electricity measurement, when the shredder is registering an Ampere of 0.
Scope: HKW or FWL
Formula: Downtime Shredder
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Starving Time Shredder- Measurement Element - Time

Description: The time the shredder is starving, due to the fact that there is no material in the shredder.
Scope: HKW or FWL
Formula: Starving Time Shredder
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Busy Time Shredder- Measurement Element - Time

Description: The time the shredder is busy, there is material in the shredder and it is busy.

Scope: HKW or FWL
Formula: Starving Time Shredder
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Production Time Measurement Elements

Below you find a list of elements that are necessary to determine the production time. These production time are related to the whole production line, the HKW or FWL, including the shredder.
Disclaimer: Planned Down Time is already excluded from all Measurement Elements.

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Time	Actual Order Execution Time
2	Measurement Element	Time	Actual Production Time
3	Measurement Element	Time	Actual Unit Production Time
4	Measurement Element	Time	Actual Unit Busy Time
5	Measurement Element	Time	Time Last Output Is Thrown In
6	Measurement Element	Time	Time Last Output Comes Out

Name: Actual Order Execution Time- Measurement Element - Time

Description: Total shift time that is set for a production batch or a measurement plan. Start Time Production: This is from the last big bag of the previous freight is tapped of and the production of the measurement freight starts. **OR** The time the adjustment of the production line start of the batch over which a measurement will be performed, e.g. that a different screen has to be installed.
End Time Production: This is from the last big bag of the measurement plan batch is tapped of and the production of the next freight starts. **OR** The time the adjustment of the production line start for the upcoming freight, e.g. that a different screen has to be installed.
This time also includes the time that the production line is down due to failure events.
Scope: HKW or FWL
Formula: Start Time Production - End Time Production
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Actual Production Time- Measurement Element - Time

Description: The time that a production batch is running or Actual Order Execution Time, excluding the time that the production line is down due to failure events.
Scope: HKW or FWL

Formula: Actual Order Execution Time - Failure Event Time
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Actual Unit Production Time- Measurement Element - Time

Description: Actual Production Time minus the time that the shredder is actually running or is busy.
Scope: HKW or FWL
Formula: Actual Busy Time - Down Time Shredder
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Name: Actual Unit Busy Time- Measurement Element - Time

Description: Actual Unit Production Time minus the time that a shredder is starving. So that the shredder is actually shredding product and in a busy state.
Scope: HKW or FWL
Formula: Actual Production Time - Starving Time Shredder (= Shredder Busy Time)
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

<table>
<tr><td colspan="4">Total Shift Time</td></tr>
<tr><td colspan="4">Actual Order Execution Time</td></tr>
<tr><td colspan="3">Actual Production Time</td><td>Failure Event Time</td></tr>
<tr><td colspan="2">Actual Unit Production Time</td><td>Shredder Down</td><td></td></tr>
<tr><td>Actual Unit Busy Time</td><td>Shredder Starving</td><td></td><td></td></tr>
</table>

Table 8: A graphic representation of the different production time elements.

We're not considering the following Measuring Elements

Reason: Establish to following 2 Measuring Elements: Time Last Output Is Thrown In and Time Last Output Comes Out. This time is hard to establish because it is a continuous flow process. The production line will slowly decrease it's output. The production in never fully empty, there is always something left. Otherwise it would be a good indicator to find out how the production process behaves when it is performing at a higher capacity.

Not Considering - Name: Time Last Output Is Thrown In - Measurement Element - Time

Description: The time that the last bale or scoop of bulk is thrown in the shredder.
Scope: HKW or FWL
Formula:
Unit of Measure: Hours:Minutes
Range: Time
Trend: NVT

Not Considering - Name: Time Last Output Comes Out - Measurement Element - Time

Description: The last time the output of the production line is at a full flow.
Scope: HKW or FWL
Formula: Time First Bale Is Thrown In
Unit of Measure: Hours:Minutes
Range: Time

Process KPIs

In chapter 3 is the definition of process KPIs and the subcategories: Production KPI, Quality KPI and Energy KPI. In addition to that you find the maintenance KPI. In the table below you find a small description of those KPIs.

Name	Description
	Process KPIs
Quality KPI	All KPIs related to the output.
Energy KPI	All KPIs related to the input that is needed in order to get an end product.
Production KPI	All KPIs related to the performance of the production process.
	Maintenance KPIs
Maintenance KPI	All KPIs related to the Failure Events of the production line.

Table 9: Short description of different KPIs

Quality KPI

These conser the KPIs related to the quality.

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Quality	Quality Ratio
2	Process KPI	Quality	Waste Ratio
3	Process KPI	Quality	By-Product
4	Process KPI	Quality	Angle Share
5	Process KPI	Quality	Slik Ratio

Name: Quality Ratio (in Company X known as: Ausbeute)

Description: The fraction of desired end product extracted from the resource input.
Scope: HKW or FWL
Formula: Product Quantity / Resource Input Quantity
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more desired end product is extracted.

Name: Waste Ratio (In ISO-22400 known as Scrap Ratio)

Description: The fraction of waste extracted from the resource input. The definition of waste in this case, is waste that Company X can't create a profitable end product with.
Scope: HKW or FWL
Formula: Product Quantity / Resource Input Quantity
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more waste is extracted.

Name: By-Product Ratio

Description: The fraction of by Product that is extracted from the resource input.
Scope: HKW
Formula: Foil Output Quantity (excluding Slik Production) / Resource Input Quantity
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more by product is extracted.

Name: Angle Share

Description: The fraction of weight that is missing when subtracting the resource input weight form all outputs weight (Waste Bin + Foil Output Quantity + End Product +). The missing weight can be explained by the variables mentioned in Measurement Plan - Possible Threat to Validity Weight.
Scope: HKW or FWL
Formula: (Input Quantity Resource - Waste Output Quantity - Foil Output Quantity - Product Output Quantity) / (Waste Output Quantity + Foil Output Quantity + Product Output Quantity)
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more by product is extracted.

For Future Use → Name: By-Product Ratio

Reason: The slik flow of both the HKW and FWL are combined towards one waste bin, so it is not possible to measure the amount of SLiks that is produced.
Description: The fraction of by Product that is extracted from the resource input.
Scope: HKW or FWL
Formula: (Foil Output Quantity + Slik Output Quantity) / Resource Input Quantity
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more by product is extracted.

For Future Use → Name: Slik Ratio

Reason: Same as mentioned above
Description: The fraction of Slik that is extracted from the resource input.
Scope: HKW or FWL

Formula: (Slik Output Quantity) / Resource Input Quantity
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more slik is produced.

Energy KPI

These KPIs conser the Energy Consumption.

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Energy	Electricity Ratio
2	Process KPI	Energy	Additive Ratio
3	Process KPI	Energy	Water Ratio
4	Process KPI	Energy	Water Ratio → Vitens Water Ratio
5	Process KPI	Energy	Water Ratio → Source Water Ratio

Name: Electricity Ratio

Description: The amount of Electricity used to produce 1 Kg of end product
Scope: HKW or FWL
Formula: (Input Quantity Electricity) / Product Quantity
Unit of Measure: kWh per Kg Product
Range: NVT
Trend: The higher the ratio, the more additives is used to produce the desired end product.

Name: Additives Ratio

Description: The amount of additives used to produce 1 Kg of end product
Scope: HKW or FWL
Formula: (Input Quantity Additives) / Product Quantity
Unit of Measure: Kg Additives per Kg Product
Range: NVT
Trend: The higher the ratio, the more additives is used to produce the desired end product.

Name: Water Ratio (can be further split into the 2 different water inputs: Vitens and Source)

Description: The amount of water used to produce 1 Kg of end product
Scope: HKW or FWL
Formula: (Input Quantity Source Water + Input Quantity Vitens Water) / Product Quantity
Unit of Measure: Liter per Kg Product
Range: NVT
Trend: The higher the ratio, the more water is used to produce the desired end product.

Split form Water Ratio → Name: Vitens Water Ratio

Description: The amount of Vitens water used to produce 1 Kg of end product
Scope: HKW or FWL
Formula: (Input Quantity Vitens Water) / Product Quantity

Unit of Measure: Liter per Kg Product
Range: 0 - 100
Trend: The higher the ratio, the more water is used to produce the desired end product.

Split form Water Ratio → Name: Source Water Ratio

Description: The amount of source water used to produce 1 Kg of end product
Scope: HKW or FWL
Formula: (Input Quantity Source Water) / Product Quantity
Unit of Measure: Liter per Kg Product
Range: 0 - 100
Trend: The higher the ratio, the more water is used to produce the desired end product.

Production KPI

These conser KPIs related to production

Nr.	Category	Sub-Category	KPI Name
1	Process KPI	Production	Availability
2	Process KPI	Production	Allocation Efficiency
3	Process KPI	Production	Utilisation Efficiency
4	Process KPI	Production	Throughput Rate During Order Execution
5	Process KPI	Production	Throughput Rate During Shredder Running Time
6	Process KPI	Production	Throughput Time First Input
7	Process KPI	Production	Throughput Time During Shredder Running Time
8	Process KPI	Production	Throughput Time During Order Execution

Name: Availability

Description: The fraction of the time that is available to produce. This is the time the line is running and not down due to a failure event.
Scope: HKW or FWL
Formula: Actual Production Time / Actual Order Execution Time
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the more time the operator has to run the production line.

Name: Allocation Efficiency

Description: The fraction of the time the shredder is up (busy and starving) and running from the available production time.
Scope: HKW or FWL
Formula: Actual Unit Production Time / Actual Production Time
Unit of Measure: Percentage (%)
Range: 0 - 100

Trend: The higher the percentage, the more the production line is adding value to the resource input.

Name: Utilisation Efficiency

Description: The fraction of the time the shredder is busy and not starving, from the available production time.
Scope: HKW or FWL
Formula: Actual Unit Busy Time / Actual Production Time
Unit of Measure: Percentage (%)
Range: 0 - 100
Trend: The higher the percentage, the better the shredder is fed.

Throughput Related KPIs (Part of Process KPIs)

Name: Throughput Rate During Order Execution

Description: Amount of output end product that is produced in one hour, during the time that the production is executed.
Scope: HKW or FWL
Formula: Product Quantity / Actual Order Execution Time
Unit of Measure: Kg Per Hour
Range: NVT
Trend: The higher the rate, the more output is produced by the production line, during the time that the order is executed.

Name: Throughput Rate During Shredder Running Time

Description: Amount of output end product that is produced in one hour, when the shredder is running. (During the time that the shredder is starving, the production line is still up and adding value to the resource input)
Scope: HKW or FWL
Formula: Product Quantity / Actual Unit Production Time
Unit of Measure: Kg Per Hour
Range: NVT
Trend: The higher the rate, the more output is produced by the production line in the time that the shredder is running.

Name: Throughput Time First Input

Description: The time the material takes to go from the input part of the shredder, to the output part of the production line. This is when the first bale/bulk is thrown in and the output spikes.
Scope: HKW or FWL
Formula: Time First Bale Thrown In - Time First Output Comes Out
Unit of Measure: HOURS:MINUTES
Range: NVT
Trend: The higher the time, the faster the material is processed on the production line.

Name: Throughput Time During Order Execution

Description: The time one kg of output it takes to be processed in the production process. The time that is used is the Actual Order Execution Time.
Scope: HKW or FWL
Formula: Actual Order Execution Time (Seconds or Minutes) / Product Quantity

Unit of Measure: Minutes (or seconds) Per Kg
Range:NVT
Trend: The higher the time, the faster the material is processed on the production line during the time that the order is executed.

Name: Throughput Time During Shredder Running Time

Description: The time one kg of output it takes to be processed in the production process. The time that is used is the Actual Unit Production Time.
Scope: HKW or FWL
Formula: Actual Unit Production Time / Product Quantity
Unit of Measure: Minutes (or seconds) Per Kg
Range: NVT
Trend: The higher the time, the faster the material is processed on the production line during the time that the shredder is up and running.

Maintenance KPIs

These conser the KPIs related to the maintenance.

Nr.	Category	Sub-Category	KPI Name
1	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio
2	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio → Failure Event Time Ratio Input Related
3	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio → Failure Event Time Ratio Production Related
4	Maintenance KPI	Maintenance KPI	Failure Event Occurrence
5	Maintenance KPI	Maintenance KPI	Failure Event Occurrence → Failure Event Occurence Input Related
6	Maintenance KPI	Maintenance KPI	Failure Event Occurrence → Failure Event Occurrence Production Related

Name: Failure Event Time Ratio (Splits into: Input and Production Related)

Description: The fraction of the time the production is down, from the available production time. **Scope:** HKW or FWL
Formula: Down Time Shredder (= Failure Event Time Input Related + Failure Event Time Production Related) / Actual Order Execution Time
Unit of Measure: Percentage (%)
Range: 0-100
Trend: The higher the percentage, the more time the production line is down and not adding value to the resource input.

Split from Failure Event Time Ratio → Name: Failure Event Time Ratio Production Related

Description: The fraction of the time the production is down due to production related failures, from the available production time.
Scope: HKW or FWL
Formula: Failure Event Time Production Related / Actual Order Execution Time
Unit of Measure: Percentage (%)
Range: 0-100
Trend: The higher the percentage, the more time the production line is down due to a failure event that is production related and not adding value to the resource input.

Split from Failure Event Time Ratio → Name: Failure Event Time Ratio Input Related

Description: The fraction of the time the production is down due to an input related failure, from the available production time.
Scope: HKW or FWL
Formula: Failure Event Time Input Related / Actual Order Execution Time
Unit of Measure: Percentage (%)
Range: 0-100
Trend: The higher the percentage, the more time the production line is down due to a failure event that is input related and not adding value to the resource input.

Name: Failure Events Occurrence (Splits into: Input and Production Related)

Description: The frequency at which a failure events occurs during the production process.
Scope: HKW or FWL
Formula: Failure Event Occurrence Input Related + Failure Event Occurrence Production Related
Unit of Measure: Integer
Range: 0-(infinity)
Trend: The higher the number, the more time the production line spend being down because of both Input and Production.

Split from Failure Events → Name: Failure Events Occurrence Input Related

Description: The frequency at which a failure events related to the input occurs during the production process.
Scope: HKW or FWL
Formula: Failure Event Occurrence Input Related
Unit of Measure: Integer
Range: 0-(infinity)
Trend: The higher the number, the more time the production line spend being down because of an input related failure event.

Split from Failure Events → Name: Failure Events Occurrence Production Related

Description: The frequency at which a failure events related to the production occurs, during the production process.
Scope: HKW or FWL
Formula: Failure Event Occurrence Production Related
Unit of Measure: Integer
Range: 0-(infinity)

Trend: **The higher the number, the more time the production line spend being down because of a production failure event.**

Nr.	Category	Sub-Category	KPI Name
1	Measurement Element	Quantity	Input Quantity Electricity
2	Measurement Element	Quantity	Input Quantity Resource
3	Measurement Element	Quantity	Input Quantity Additive
4	Measurement Element	Quantity	Input Quantity Source Water
5	Measurement Element	Quantity	Input Quantity Vitens Water
6	Measurement Element	Quantity	Product Output Quantity
7	Measurement Element	Quantity	Foil Output Quantity
8	Measurement Element	Quantity	Waste Output Quantity
9	Measurement Element	Quantity	Slik Output Quantity
9	Measurement Element	Quantity	Angle Share Quantity
10	Measurement Element	Quantity	Failure Event Occurrence
11	Measurement Element	Quantity	Failure Event Occurrence Production Related
12	Measurement Element	Quantity	Failure Event Occurrence Input Related
13	Measurement Element	Time	Failure Event Time
14	Measurement Element	Time	Failure Event Time Input Related
15	Measurement Element	Time	Failure Event Time Production Related
16	Measurement Element	Time	Time First Bale Thrown In
17	Measurement Element	Time	Time First Output Comes Out
18	Measurement Element	Time	Starting Time Production
19	Measurement Element	Time	Ending Time Production
20	Measurement Element	Time	Up Time Shredder

21	Measurement Element	Time	Down Time Shredder
22	Measurement Element	Time	Starving Time Shredder
23	Measurement Element	Time	Busy Time Shredder
24	Measurement Element	Time	Actual Order Execution Time
25	Measurement Element	Time	Actual Production Time
26	Measurement Element	Time	Actual Unit Production Time
27	Measurement Element	Time	Actual Unit Busy Time
28	Measurement Element	Time	Time Last Output Is Thrown In
29	Measurement Element	Time	Time Last Output Comes Out
30	Process KPI	Quality	Quality Ratio
31	Process KPI	Quality	Waste Ratio
32	Process KPI	Quality	By-Product
33	Process KPI	Quality	Angle Share
33	Process KPI	Quality	Slik Ratio
34	Process KPI	Energy	Electricity Ratio
34	Process KPI	Energy	Additive Ratio
35	Process KPI	Energy	Water Ratio
36	Process KPI	Energy	Water Ratio → Vitens Water Ratio
37	Process KPI	Energy	Water Ratio → Source Water Ratio
38	Process KPI	Production	Availability
39	Process KPI	Production	Allocation Efficiency
40	Process KPI	Production	Utilisation Efficiency
41	Process KPI	Production	Throughput Rate During Order Execution
42	Process KPI	Production	Throughput Rate During Shredder Running Time
43	Process KPI	Production	Throughput Time First Input
44	Process KPI	Production	Throughput Time During Shredder Running Time
45	Process KPI	Production	Throughput Time During Order Execution
46	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio

47	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio → Failure Event Time Ratio Input Related
48	Maintenance KPI	Maintenance KPI	Failure Event Time Ratio → Failure Event Time Ratio Production Related
49	Maintenance KPI	Maintenance KPI	Failure Event Occurrence
50	Maintenance KPI	Maintenance KPI	Failure Event Occurrence → Failure Event Occurence Input Related
51	Maintenance KPI	Maintenance KPI	Failure Event Occurrence → Failure Event Occurrence Production Related
52	Measurement Element	Quantity	Value Added
53	Process KPI	Quality	Value Added per ton Output
54	Process KPI	Quality	Value Added per ton Input
55	Process KPI	Quality	Freight Score
56	Process KPI	Quality	Average Freight Score Past 5 Deliveries
57	Process KPI	Quality	Average Freight Score Past Year
58	Process KPI	Quality	Average Score 2 Months Previous Year

E.2 Inventory of Company KPIs

Inventory Current KPIs

KPI	Parameters	Unit of Measure	Production Line
RP Kg per Week 2019 : material type is specified but nothing more.			
Waste	Waste	Kg	FWL
Waste	Waste	Kg/Hour	FWL
Waste	Waste	Kg	HKW
Waste	Sand/Slick	Kg	FWL & HKW
Waste	Sand/Slick	Kg/Hour	FWL & HKW
Machine Hours	Machine Hours	Hour	HKW
Waste	Water Usage	m3	HKW
Waste	Water Usage	m3/hour	HKW
Output	Absolute Ready Product	Kg	FWL & HKW
RP Productie 2019 - FolieWaslijn: they are all linked to a specific input, no reference number no supplier. And to a timeframe. No data on output is known, this is because they send it directly to the extruder 4 or 2			
Utilisation	Hours Shredder	Hours/ M3?	FWL
Waste	Waterlevel	Liters	FWL
Waste	Sand/Slick	Kg	FWL
Waste	Waste	Kg	FWL
Productionsheets - FWL : Only material is described and the used bales are with a reference number			
Utilisation	Time	Hours	FWL
Waste	Waterlevel	Kg	FWL
RP Productie 2019 - Extruder 4			
?!?!?!?!?!?!			
RP Productie 2019 - HK Waslijn. Linked to Input material, supplier and has reference number.			
Waste	Waste	Kg	HKW
Waste	Waterlevel	Liters	HKW
Utilisation	Hour	Hours	HKW
Output	Bruto Weight	Kg	HKW
Output	Netto Weight	Kg	HKW

Output	Recovery Percentage (Ausbeute)	Kg	HKW
Waste	PE-Content	Percentage	HKW
Waste	Missing Weight	Kg	HKW
Waste	Foil	Kg	HKW
Output	End Product	KG	HKW
Productionsheets - HKW: stickers with material description and reference number of load.			
Waste	Solid Waste	Kg	HKW
Waste	Waste Foil Separator	Kg	HKW
Waste	Waterlevel	Kg	HKW
Output	End Product	Kg	HKW
Utilisation	Time	Hours	HKW

E.3 Inventory Supporting KPIs

Name: Value Added - Measuring Element - Quantity

1. Description: Selling Price End Product - Total Costs Input - Overhead Production Line - Failure Event Time - Overhead Total Company
2. Scope: From the resource input of the washing line until the output.
3. Formula: Selling Price End Product - Total Costs Input - Overhead Production Line - Failure Event Time - Overhead Total Company
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: NVT

Name: Value Added per ton output - Process KPI - Quality

1. Description: The value added per ton output
2. Scope: From the resource input of the washing line until the output.
3. Formula: Value Added / Product Output Quantity
4. Unit of Measure: Currency
5. Range: NVT
6. Trend:The more value is added relative to the output.

Name: Value Added per ton input - Process KPI - Quality

1. Description: The value added per ton input
2. Scope: From the resource input of the washing line until the output.
3. Formula: Value Added / Resource Input Quantity
4. Unit of Measure: Currency
5. Range: NVT
6. Trend: The more value is added relative to the input.

Appendix F

Literature Study

F.1 Overview of KPIs Literature Study

Perspective source		Process KPIs	
	Production	Quality	Energy
Key performance indicators for manufacturing operations management in the process industry	Throughput rate	Quality ratio	Energy Consumption
	Technical efficiency	Actual to planned scrap ratio	
		Scrap ratio	
		Finished goods ratio	
Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard	Availability	Actual to scrap ratio	Comprehensive energy consumption
	First pass yield	production loss ratio	
	Critical process capability index	rework ratio	
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	process capability index	scrap ratio	
		Other loss ratio	
		Finished goods ratio	
		Integrated goods ratio	
		Throughput rate	
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	Availability	Actual to planned scrap ratio	
	Allocative efficiency	Scrap ratio	
	Technical efficiency	Rework ratio	
	Utilization efficiency	Fall of ratio	
	Effectiveness	First time quality	

	Allocation ratio	Quality buy ratio	
	Production process ratio		
	Throughput rate		
	Setup ratio		
	Line throughput rate		
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach	Resource and production data (needed)	Resource and production data (needed)	Resource data (needed)
Key Performance Indicators Improve Industrial Performance	Percentage Scheduled operation time	Percentage of full quality product	Energy input / Produced output
	Percentage actual uptime	Raw-material input / Produced output	
		Emission / Produced output	
		Waste deposit / Produced output	
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems		Scrap Ratio	
		Quality Ratio	

Table: 2. Measurement elements

Perspective source	Measurement elements	
	Time	**Quantity**
Key performance indicators for manufacturing operations management in the process industry	Planned Operation Time	Input Quantity
	Actual busy time	Raw Material Quantity
	Actual downtime	Energy medium quantity
	Actual production time	Output quantity
		Desired quantity
		By-product quantity

		Scrap quantity
Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard		Comprehensive energy consumption
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	Actual unit delay time	Good part
	Actual order execution time	Good quantity
	Planned run time per item	Equipment production capacity
	Actual unit busy time	Actual production
	Actual unit processing time	Rework quantity
	Actual unit setup time	Scrap quantity
	Planned busy time	Integrated good quantity
	Preventive maintenance time	Inspected part
	Operating time between failures	Machine capability index
	Time to failure	Other loss
	Time to repair	Production loss
	Corrective maintenance time	Failure event
		Lower specification limit
		upper specification limit
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	Actual unit processing time	Good quantity
	Actual production time	Scrap Quantity
	Actual unit setup time	PLanned scrap quantity
	Actual unit down time	produced quantity in the first operation process
	Actual unit idle time	
	Actual unit busy time	
	Actual order execution time	

	Actual transportation time	
	Time to failure	
	Operating time between failures	
	Time to repair	
	Failure event	
	Corrective maintenance time	
	Preventive maintenance time	
	Blocking time	
	Starving time	
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach	Process cycle times	Conveyor speeds
	Process setup times	Resource/process energy consumption
	Resource mean time between failure	Process scrap percentage
	Resource mean time to repair	
Key Performance Indicators Improve Industrial Performance	Operating Hours	E.G. heat transfer rate of heat exchanger
	Operating speed	E.g. Number of valve openings
	load	E.g. Vibration amplitude
	Startup	
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	Actual unit busy time	Scrap quantity
	Actual production time	Good quantity
	Planned busy time	Produced quantity

Perspective source		Added by theory from: A Hierarchical structure of key performance indicators

		for operation management and continuous improvement in production systems
	Equipment KPIs	Maintenance KPIs
Key performance indicators for manufacturing operations management in the process industry	Allocation ratio	
	Equipment load ratio	
	Utilization efficiency	
Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard	Technical efficiency	Mean operating time between failures
Focusses a lot on KPIs related to inventory and personnel, on which we don't focus.	Effectiveness	mean time to repair
	Production process ratio	Corrective maintenance ratio
	Machine capability index	
	equipment load ratio	
	Critical machine capability index	
	net equipment effectiveness index	
	Overall equipment effectiveness index	
	Fall of ratio	
	Setup ratio	
	Utilization efficiency	
A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	Buffer capacity	Mean time to failure
	Blockage ratio	Mean time to repair
	Starvation ratio	

	Work in process	Mean delay time
	Overall Equipment effectiveness	Corrective maintenance ratio
	Net equipment effectiveness	
	Mean setup time	
	Mean operating time between failures	
Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach		
Key Performance Indicators Improve Industrial Performance	Percentage production rate of max rate	Maintenance costs / Produced output over a time period.
	OEE	Maintenance time / Produced output over a time period.
		Number of alarms over a time period
		Equipment ware
Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	Allocation Efficiency	
	Availability	
	Utilization efficiency	

Overview of Literature list

Webster & Watson (2002) described the following 4-steps to do a systematic literature review:

The research question that will be answered is:

What KPIs are relevant to the performance of a production line?

1. Define the keywords, search strings, and inclusion & exclusion criteria to search in scientific databases such as Scopus and Web of Science. The following was used to find relevant articles:
    a. Search String: Production Process AND KPI, Dashboard and KPI

	Production line/process	KPI	Dashboard	Manufacturing	Search String
Search 1	x	x			"Production process" AND KPI
Search 2		x	x		"KPI" AND "Dashboard"
Search 3		x		x	"KPI" AND "Manufacturing"

b. Date Range: 1990 - Present. Dashboards weren't used until 1990.

c. Inclusion and Exclusion criteria:

Nr	In- or Exclusion Criteria	Reason
1	Include: all articles from 1990 - present	Dashboards weren't available before that time
2	Exclude: Journals:Computer Science, Materials Science, Chemical Engineering, Mathematics, Computer Science	Is not the industry to which this is relevant
3	Exclude: Non-Dutch and Non-English Articles	Hard to read

Search results

Search Protocol for Scopus	Scope	Date of search	Date range	Number of entries
KPI AND production line	Title, Keywords and Abstract	23-4-2019	1990-present	45
KPI AND Dashboard	Title, Keywords and Abstract	23-4-2020	1990-present	86
Manufacturing AND KPI	Title, Keywords and Abstract	24-4-2020	1990-present	312
Total Endnote				443

Selecting based on inclusion/exclusion criteria				433
Selecting based on availability				72
Removing duplicates				45
Total Read				24
Included after complete reading				6

Literature list of articles found in literature review

Nr	Journal	Authors	Title	Citations	Publisher
1	International Journal of Production Research	A. Mousavi, H.R.A. Siervo	A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	219	Taylor & Francis
2	Performance metrics for Intelligent Systems (PerMIS) Workshop	J. Arinez, S.Biller	Benchmarking Production System, Process Energy, and Facility Energy Performance using a system approach	24	PerMIS
3		Li Zhu, Charlotta Johnsson, Jaco Mejbik, Martina Varisco, Massimiliano Schiraldi	Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard	14	IEEM
4	IEEE Internal Conference on Industrial Engineering and Engineering Management	Li Zhu, Charlotta Johnsson, Jaco Mejbik, Martina Varisco, Massimiliano Schiraldi	Key Performance Indicators for Manufacturing Operations Management in the Process Industry	12	IEEM
5	The 7th International Conference on Applied Energy	Carl-Fredrik Lindberg, SieTing Tan, JinYue Yan, Fredrik Starfelt	Key performance indicators improve industrial performance	56	Elsevier
6	IEEE Industrial Cyber-Physical Systems	Muhammad, U.; Ferrer, B.R.; Mohammed, W.M.;Lastra, J.L.M.	Implementing and Visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems	21	Machines

Short summary of article listed above. Numbers correspond to the articles in the list.

Nr	Summary
1	This paper gives a good overview of a lot of possible KPIs. A good overview of the different categories of KPIs, and also a lot of the mutual relationships and dependencies between KPIs. There are also a lot of formulas on how to calculate the KPIs.

2	This paper gives an handle to make a conceptual design of the manufacturing system. It gives the basic requirements that are needed to make a conceptual design analysis: 1. Process flow, 2. production statistics, 3. resource - equipment list,4. energy resources. It also gives a good handle to look at how energy consumption data can be used to find the state (idle/busy/down) of the production equipment. This can be used to determine down and up time and effectiveness of the equipment. But we don't want to make a simulation model, but it give s a good insight in how you might do data collection.
3	This paper is similar to KPI for manufacturing operations management in the process industry. It claims that there is a gap between ISO 22400 and the process industrial needs. It has 3 main gaps: 1. Only few of defined KPIs are suitable for the process industry, 2. relationships and working conditions of each unit are different, 3. Some defined KPIs cannot be computed or even meaningless. It proposes some alterations, or removals of certain KPIs. It proposes a different method to calculate Utilisation, setup and Allocation.
4	This focuses on process industry with continuous processes, instead of the discrete industry. It comes up with a novel framework for organizing KPIs and associated measurement elements. KPIs can organised in 3 parts, the equipment KPIs and the process KPIs and the measurement elements.
5	This paper gives an alternative to benchmarking results. The first thing to do is to identify the process signals that are strongest correlated with the KPI and then change these process signals in the directions that improves the KPI. It suggest to identify waste in different forms, and reduces that waste to improve performance. It also proposes a method on identifying process signals or combinations of process signals that are strongly correlated with the KPI of interest.
6	Give a short summary of the whole process for implementing KPIs and many background information. It contains information about current KPIs. A description of an approach with technical details and conceptual details. Also a case is discussed in which they implement the KPIs with the dashboard. They give a overview of the result of the implementation with the used KPIs.

The concepts that are derived from the theory are listed below. The use and the integration of these theories are also listed below.

Nr	Integration of Theory
1	I'll be looking at possible relations Between KPIs in my research. Also use these formulas to calculate KPIs
2	It will help with the description of the production line and give an insight in how we might measure energy consumption.
3	Discussed KPIs will be further looked at and possibly used
4	Framework for integrating KPIs will be used to get a good overview of the used KPIs and their calculation. There are also useful KPIs that can be useful for my research
5	Process signals will be definitely used to get insight in the state of the production process in order to get .
6	I will use approach to give me an idea on how to structure my implementation process.

Nr	Concepts	
1	Interdependencies, relationships	Certain KPIs are dependent on each other. For example they have parameters in common to calculate the KPIs.
2	Process flow	A description of the flow of the resource throughout the production process.
	production statistics	Parameters relating to production that are needed to calculate the KPIs
	resource- equipment list	Inventory of all the resources that are used as input, and an inventory of all the equipment or machines in the production process.
3	Process industry	Industrie where the production process occurs in batch of materials that is indistinguishable.
3	Discrete industry	Industry where the production is made of distinct items.
4	Production Modality	The characteristic of the output of a production process, e.g. Continuous flow or a discrete entity
	Production form	The shape of the production, for example fluid-based or Pieces and parts
	Work unit	How the process is organised, e.g. unit, work cell
5	Process Signals	Parameters that are needed to calculate the KPIs, that are relevant to the production process.
	Energy KPIs	The energy could be in different forms for example electricity, gas, coal, oil, biomass, steam, etc. The produced output could e.g. be in units of tons/h, m3 /h, units/h, etc.
	Raw Material KPIs	Raw-materials may not only be the main raw-material for a plant, it could also be water, chemicals, etc.
	Operation KPIs	The main Operation KPI is the Overall Equipment Effectiveness (OEE) [15] and its individual parts
	Control performance KPIs	Control performance may influence product quality, production speed, equipment wear, etc.
	Maintenance KPIs	Too little maintenance causes an excessive number of unplanned stops resulting in lost production and emergency maintenance. Too much maintenance causes large maintenance costs and lost production during each planned maintenance.
	Equipment KPIs	Equipment KPIs These KPIs can be used to follow the condition of equipment and in some cases also predict when maintenance will be required.
6	KPI description	See table below
	Effect model diagram	

Table 1: Structure of KPI description according to ISO 22400.

	KPI Description
Content	
Name	Name of the KPI
ID	A user defined unique identification of the KPI in the user environment
Description	A brief description of the KPI
Scope	Identification of the element that the KPI is relevant for, which can be a work unit, work center or production order, product or personnel
Formula	The mathematical formula of the KPI specified in terms of elements
Unit of measure	The basic unit or dimension in which the KPI is expressed
Range	Specifies the upper and lower logical limits of the KPI
Trend	Is the information about the improvement direction, higher is better or lower is better
Context	
Timing	A KPI can be calculated either in real-time: after each new data acquisition event on demand: after a specific data selection request periodically: done at a certain interval, e.g., once per day
Audience	Audience is the user group typically using this KPI. The user groups used in this part of ISO 22400 are Operators: personnel responsible for the direct operation of the equipment Supervisors: personnel responsible for directing the activities of the operators Management: personnel responsible for the overall execution of production
Production methodology	Specifies the production methodology that the KPI is generally applicable for Discrete Batch Continuous
Effect model diagram	The effect model diagram is a graphical representation of the dependencies of the KPI elements that can be used to drill down and understand the source of the element values

	NOTE This is a quick analysis which supports rapid efficiency improvement by corrective actions, and thus reduces errors
Notes	Can contain additional information related to the KPI. Typical examples are Constraints Usage Other information

Appendix J: Theoretical Framework

Process Industry Framework

A framework is used from **Key Performance indicators for manufacturing operations management in the process industry** (Li Zhu, 2017). It will help with the structuring of the KPIs and the associated measurement elements. The production company that I conduct my research at is a processing company.

Measurement elements

Basic measurements, called measurement elements have to be collected in order to calculate KPIs. According to ISO 22400 Part 2, these elements - i.e. the "relevant measurements for use in the formula of a key performance indicator" - can be divided into three main categories; time, quality and logistical. The logistical elements contain both quantity and inventory measurements. In this project, the focus will be on the two categories time and quantity measurement elements.

The **time** measurement elements are comprised of data related to the duration of the production process.The time measurement elements are comprised of data related to the duration of the production process, including planned operation time and actual operation time. Moreover, the actual operation time can be divided into production time and downtime to increase the level of detail. The time elements are similar to the definitions in ISO 22400.

Something to consider is that in the process industry, according to this paper, it is likely that the product or the **quantity** of the product being processed in a certain production unit is difficult to measure, and often only become available in the logistical measurement elements. This can for example be measuring the weight of a processed load by subtracting the weight of a loaded truck and the weight of the unloaded truck. And also the weight of the end product in the loaded big bags, because they are weight by the forklift operators.

Equipment KPIs and Process KPIs

KPIs for the process industry can be analyzed from 2 levels: process KPIs and equipment KPIs. The performance of the production equipment is directly influenced by the performance of the production equipment.

Process KPIs can be divided into three categories: production, quality and energy KPIs. The equipment KPIs include allocation ratio, utilization efficiency and equipment load ratio. See figure 1 for a schematic overview.

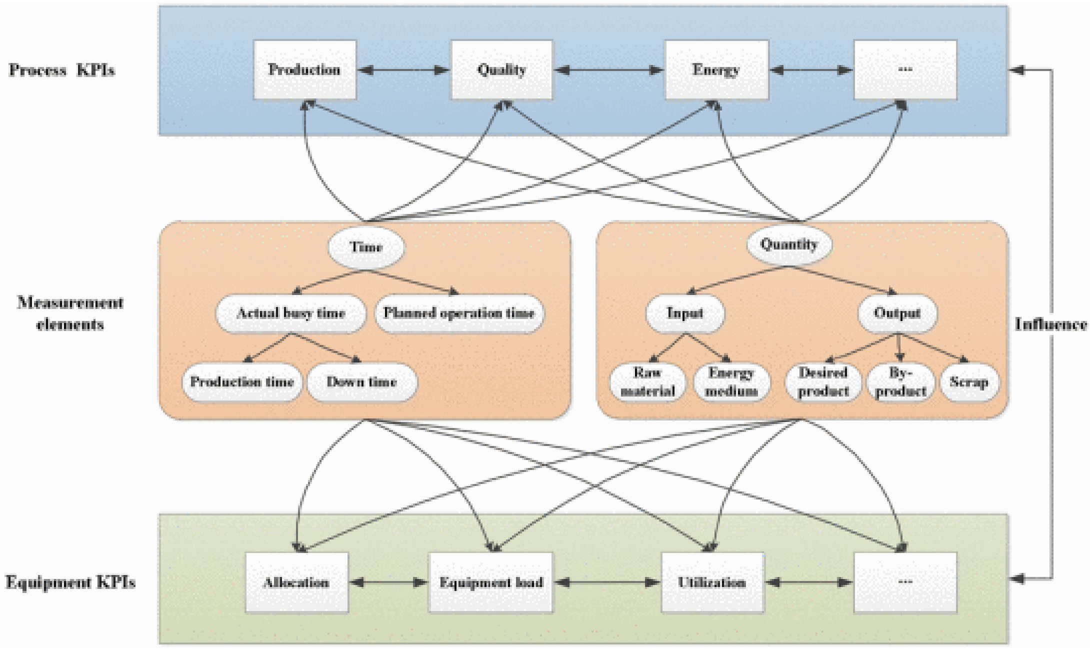


Figure 1: Framework of KPIs

Integration of theory

This theory will help with determining the efficiency of a production line of a process industry, so that I can have a better and more relevant approach to my project. The company at which I do my research is a processing company. I can calculate KPIs better, because they are better applicable to my project.

Theoretical Framework with KPIs that can be considered.

In figure 1 there is a framework lay-out. Below you can find the different elements, process KPIs, measurement elements and equipment KPIs put into a scheme. KPIs from other articles are also listed here. The KPIs that will be used in my project are yet to be determined.

1. A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems [8]

2. Key performance indicators for manufacturing operations management in the process industry [11]

3. Benchmarking Production System, Process Energy, and Facility Energy Performance Using a Systems Approach [2]

4. Key Performance Indicators Improve Industrial Performance [12]

5. Implementing and visualizing ISO 22400 Key Performance Indicators for Monitoring Discrete Manufacturing Systems [13]

6. Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard [14]

Appendix G

Quality Check from the “Acceptatiebeleid versie 13.01.2015

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Appendix H

“Der Grüne Punkt” - 324 - Polypropylene

Product Specification 05/2012
Fraction-No. 324
Sorting fraction: P O L Y P R O P Y L E N E

A Specification/Description

Used, residue-drained, rigid, system-compatible items made of polypropylene, volume 5 litres, e.g. bottles, bottles, cups and trays, incl. secondary components such as lids, labels etc.

The supplement is part of this specification!

B Purity

At least 94 % by mass according to specification/description.

C Impurities

Max. total amount of impurities 6 % by mass
Metallic and mineral impurities with a unit weight of > 100 g and cartridges for sealants are not permitted!
Other metal items < 0.5 % by mass
Rigid PE items < 1 % by mass
Expanded plastics incl. EPS items < 0.5 % by mass
Plastic films < 2 % by mass
Other residues < 3 % by mass
Examples of impurities:

1. Glass
2. Paper, Board, Cardboard
3. Composite paper/cardboard materials (e.g. liquid packaging boards)
4. Aluminised plastics
5. Other materials (e.g. rubber, stones, wood, textiles, nappies)

6. Compostable waste (e.g. food, garden waste)

Form of Delivery

1. Transportable bales
2. Dimension and density of the bales must be chosen so as to ensure that a tarpaulin truck (loading area 12.60 m x 2.40 m; lateral loading height min. 2.60 m) can be loaded with a minimum loading of 17 t
3. Dry-stored Produced with customary bale presses
4. Identified with DSD bale label stating the sorting plant no., fraction no. and production Date

H.1 Waste Framework Directive

End-of-waste criteria
What are the end-of-waste criteria, and why are they needed?
End-of-waste criteria specify when certain waste ceases to be waste and obtains a status of a product (or a secondary raw material).
According to Article 6 (1) and (2) of the Waste Framework Directive 2008/98/EC, certain specified waste shall cease to be waste when it has undergone a recovery (including recycling) operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

1. the substance or object is commonly used for specific purposes;
2. there is an existing market or demand for the substance or object;
3. the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);
4. the use will not lead to overall adverse environmental or human health impacts.

Such criteria should be set for specific materials by the Commission using the procedure described in Article 39(2) of the Waste Framework Directive (so called "comitology"). A mandate to set end-of-waste criteria was introduced to provide a high level of environmental protection and an environmental and economic benefit. They aim to further encourage recycling in the EU by creating legal certainty and a level playing field as well as removing unnecessary administrative burden.

H.2 Plastic Recyclers Europe: Bales Characterization Guidelines: HDPE Bales

Characteristics	Description
Resin	*Indicate the type of targeted resin (see glossary)*
Product & thickness	*Indicate the type of product & thickness (see glossary)*
Origin	*Indicate the origin of the waste (see glossary)*
Source	*Indicate the market stream of the waste (see glossary)*
Colour	*Indicate colour (see glossary)*
PP content (min %)	*Indicate the minimum content of PP*
Impurities	
Impurities content (max %)	*Indicate the total maximum content*
Metals (max %)	*Indicate the maximum content*
Paper (max %)	*Indicate the maximum content*
PVC (max %)	*Indicate the maximum content*
PE-LD (max %)	*Indicate the maximum content*
PE-HD (max %)	*Indicate the maximum content*
PE-LLD (max %)	*Indicate the maximum content*
Other plastics (max %)	*Indicate the maximum content*
Other impurities (max %)	*Indicate the maximum content*
Prohibited Impurities	Hazardous waste, Medical waste, Glass, Minerals, Oxo- or biodegradable material, Food contamination, Silicone, EPS & PUR
Moisture (max %)	*Indicate the maximum content*
Transport	Stable and stackable bales
Transport/contract documents	The documents will be provided with the bales
Truck load (min, tonne)	
Supplier's information	
Company name	
Company address	
Additional sorting information	
Date	

Figure H.1: Plastic Recyclers Europe: Bales Characterization Guidelines: HDPE Bales

H.3 Plastic Recyclers Europe: Bales Characterization Guidelines: PP Films

Characteristics	Description
Resin	*Indicate the type of targeted resin (see glossary)*
Product & thickness	*Indicate the type of product & thickness (see glossary)*
Origin	*Indicate the origin of the waste (see glossary)*
Source	*Indicate the market stream of the waste (see glossary)*
Colour	*Indicate colour (see glossary)*
PP content (min %)	*Indicate the minimum content of PP*
Impurities	
Impurities content (max %)	*Indicate the total maximum content*
Metals (max %)	*Indicate the maximum content*
Paper (max %)	*Indicate the maximum content*
PVC (max %)	*Indicate the maximum content*
PE-LD (max %)	*Indicate the maximum content*
PE-HD (max %)	*Indicate the maximum content*
PE-LLD (max %)	*Indicate the maximum content*
Other plastics (max %)	*Indicate the maximum content*
Other impurities (max %)	*Indicate the maximum content*
Prohibited Impurities	Hazardous waste, Medical waste, Glass, Minerals, Oxo- or biodegradable material, Food contamination, Silicone, EPS & PUR
Moisture (max %)	*Indicate the maximum content*
Transport	Stable and stackable bales
Transport/contract documents	The documents will be provided with the bales
Truck load (min, tonne)	
Supplier's information	
Company name	
Company address	
Additional sorting information	
Date	

Figure H.2: Plastic Recyclers Europe: Bales Characterization Guidelines: PP Films

Appendix I

Characterisation of Waste according to ISO

In this table you can find the effect that a certain parameter has on the production process. The number below corresponds to the number in the table above.

Property	**Status (test method)**
Batch size	Required (weight or volume)
Colour	Required (visual assessment)
Form of waste	Required (e.g. flake, film, bottle)
History of waste	Required (EN 15343)
Main polymer present	Required (percentage by weight if known)
Other polymers present	Required (percentages by weight if known)
Type of packaging in which the waste is present	Required Impact Strength Optional (EN ISO 179-1 and EN 179-2 or EN ISO 180)
Melt mass flow rate	Optional (EN ISO 1133)
Vicat softening temperature	Optional (EN ISO 306 Method A)
Additives, contaminants, moisture, volatile	Optional
Ash content	Optional (EN ISO 3451-1)
Moisture	Optional (EN 12099)
Tensile strain at break	Optional (EN ISO 527, parts 1 to 3)
Tensile strain at yield	Optional (EN ISO 527, parts 1 to 3)
Volatiles	Optional (Weight loss at a process temperature)

Appendix J

Mail Sustainability Research

Original In Dutch:
Eerst en vooral, ik kan jouw onderzoek alleen maar aanmoedigen. Een goed overzicht over de verschillende parameters die de productie beïnvloeden is belangrijk voor zowel de economische gezondheid als voor de duurzaamheid van het product/bedrijf.
In een economische analyse worden vaak (kost)prijzen gekoppeld aan energie of materiaalstromen, in een duurzaamheidsanalyse wordt de impact op het klimaat gekoppeld aan deze “material flows”. Concreet betekent dit dat wij in ons onderzoek een vereenvoudigd model maken van een productieproces (in dit geval het wassen en extruderen van gerecycleerd plastiek). In dit model proberen wij alle “material and energy flows” in kaart te brengen, dit voor een bepaalde functionele eenheid. Gezien het “sirkulær plast” project voornamelijk focust op het gebruik van gerecycleerd plastiek, is de functionele eenheid in dit project 1 kg gerecycleerd HPDE/PP uit de extruder.
De scope van het ons project is om een algemeen overzicht te krijgen over de duurzaamheid van gerecycleerd plastiek, daarom is informatie over het “gemiddelde” verbruik voldoende. Aangezien het verbruik hoogstwaarschijnlijk varieert over verschillende maanden, baseren we ons op het verbruik (en de productie) van een volledig jaar. Indien een standaardafwijking beschikbaar is voor deze waarden is dit zeer interessant voor een simulatie van de onzekerheid.
In ons model is het wassen en extruderen van plastiek gemodelleerd als twee verschillende processen. Verbruikt wordt dus altijd gemeten ten opzichte van de output (of input) in deze twee processen. Meer concreet focusseren wij ons of de volgende material en energy flows. Indien er nog belangrijke input zijn in het proces, hoor ik het graag van jou.

1. Waterverbuik in de waslijn en voor extruder (focus op verbruik, water dat wordt hergebruikt in een closed loop wordt niet onder verbuik gerekend).

2. Stroomverbuik in de waslijn en extruder. Indien bepaalds types plastiek extra behandelingsprocessen ondergaan, wordt het stroomverbuik van deze processen toegewezen aan deze types plastiek. Indien er andere energiebronnen gebruikt worden (bv opwarming van het gebouw via aardgas), worden ook deze energiebronnen geïncludeerd in de analyse.

3. Gebruik van chemicaliën (detergent) in het wasproces, indien er bepaalde waterzuiveringsactviteiten worden ondernomen worden deze ook geïncludeerd in het model.

4. Materiaalverlies tijdens het wassen en extruderen. Uit vorige studies is gebleken dat het verlies van materiaal tijdens het recycleren een beduidend effect kan hebben op de totale duurzaamheid van het proces. Voornamelijk tijdens het wasproces. Ook wat er achteraf gebeurt met het afval is zeer belangrijk, momenteel wordt aangenomen dat dit verbrand wordt.

Als ik het goed begrepen heb, analyseer jij vooral welke parameters een beduidende invloed hebben op de bovenvermelde materiaal en energiestromen? Klop dit? Heb je al bepaald conclusies die je kan delen? Welke parameters ben je aan het bekijken? Met betrekking tot het verbruik van bovenvermelde “material and energy flows” zijn volgende vraagstukken interessant:

1. Is er een verschil in tussen harde plastiek en folie?

2. Is er een verschil tussen PP en HPDE?

3. Hoe groot is het verschil tussen het “beste” en het “slechtste” scenario? Bijvoorbeeld (lage kwaliteit van input material vs hoge kwaliteit van input materiaal).

Vriendelijke groeten,
XX

Translated version:

First and foremost, I can only encourage your research. A good overview of the various parameters that influence production is important for both the economic health and the sustainability of the product / company.
In an economic analysis, (cost) prices are often linked to energy or material flows, in a sustainability analysis the climate impact is linked to these "material flows". In concrete terms, this means that in our research we make a simplified model of a production process (in this case, washing and extruding recycled plastic). In this model we try to map all material and energy flows for a specific functional unit. Given that the "sirkulær plast" project focuses primarily on the use of recycled plastic, the functional unit in this project is 1 kg of recycled HPDE / PP from the extruder.
The scope of our project is to get a general overview about the sustainability of recycled plastic, therefore information about the "average" consumption is sufficient. Since the consumption probably varies over the course of the months, we base ourselves on the consumption (and production) of a full year. If a standard deviation is available for these values, then it is very interesting for an uncertainty simulation.
In our model, the washing and extruding of plastic is modeled as two different processes. Consumption is therefore always measured in relation to the output (or input) in these two processes. More specifically, we focus on the following material and energy flows. If there is

still important input in the process, then I would love to hear it from you.

1. Water consumption in the washing line and for extruder (focus on consumption, water that is reused in a closed loop is not included in consumption).
2. Power consumption in the washing line and extruder. If certain types of plastic undergo additional treatment processes, then the power consumption of these processes is assigned to these types of plastic. If other energy sources are used (eg heating the building via natural gas), then these energy sources are also included in the analysis.
3. Use of chemicals (detergent) in the washing process, if certain water purification activities are undertaken, then these are also included in the model.
4. Loss of material during washing and extruding. Previous studies have shown that the loss of material during recycling can have a significant effect on the overall sustainability of the process. Mainly during the washing process. What happens afterwards with the waste is also very important, it is currently assumed that this is incinerated.

If I understand correctly, you mainly analyze which parameters have a significant influence on the above-mentioned material and energy flows? Is this correct? Do you already have conclusions that you can share? Which parameters are you viewing? With regard to the consumption of the above-mentioned material and energy flows, the following issues are interesting:

1. Is there a difference between hard plastic and foil?
2. Is there a difference between PP and HPDE?
3. How big is the difference between the "best" and the "worst" scenario? For example (low quality of input material vs high quality of input material).

Appendix K

Measuring Guide

K.1 Stroommeting voor Dummies

K.2 Measurement Device Installing Guide

- Confidential -

Appendix L

Costs Analysis

- Confidential -

Table L.1: Costs Analysis Overview

- confidential -

Table L.2: Overview Costs Analysis FWL

- confidential -

Table L.3: Overview Costs Analysis HKW

- confidential -

Table L.4: Costs Analysis FWL per Hour

- confidential -

Table L.5: Costs Analysis HKW per Hour

- confidential -

L.1 Electricity

- confidential -

L.2 Water Cleaning

- confidential -

Appendix M

Results MP

M.1 Measurement: Cups

- confidential -

M.2 Measurement: PP Mono Shred

- confidential -

M.3 Measurement: PP/PE Caps

- confidential - **OUTPUT PER TON INPUT IS NOT CORRECT BY ALL MEASUREMENTS LAST UPDATE OF ALL SCORES: 19-08-2019**