BACHELOR THESIS

Optimizing the process of nitrite measurement

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Due to confidentiality, all company specific information is excluded. For questions regarding the thesis, please contact the author.

AkzoNobel
SPECIALTY CHEMICALS

Bachelor thesis
Optimizing the process of nitrite measurement

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PREFACE

This bachelor report "How can the process of nitrite measurement be optimized?" describes a research to implement an in-line nitrite measurement system. This research is conducted at AkzoNobel in Hengelo from March until July 2018.

I would like to thank all the employees of Salt Specialties including the operators, the management and all other teams that helped me in my research. Especially, X which is my supervisor at AkzoNobel, helped me a lot. Due to our discussions and constructive meetings, the outcomes of this bachelor report are even better.

I have learned more about reporting a scientifically well-structured report with the help of my supervisors at the University of Twente which are Dr.ir. Petra Hoffmann and Dr.M.C. Matthieu van der Heijden. I am also very thankful for that.

I hope that you will enjoy reading this report!

Arthur Kambartsumjan

MANAGEMENT SUMMARY

AkzoNobel is a paints and coatings company and major producer of specialty chemicals. Headquartered in Amsterdam, the company has activities in more than 80 countries and employs approximately 45,000 people. This bachelor report is written in collaboration with AkzoNobel Hengelo. AkzoNobel Hengelo is one of the production locations of AkzoNobel where salt products are produced. These salt products are, for example, demanded by the meat industry. The meat industry demands a specific salt product: nitrite salt. This salt ensures that the meat turns red and that the meat will have a longer shelf life. The nitrite in the salt is added in different concentrations. These nitrite concentrations have to be measured in order to ensure that these concentrations satisfy the specific customer specifications. Otherwise, the customer claims the product. This process of nitrite measurement needs to be improved at AkzoNobel Hengelo at different production lines. To be specifically, this process of nitrite measurement needs to be in-line. With in-line is meant that the analyzer is implemented inside the process and the process is analyzed continuous. The structure within this research is as follows:

Identification of the nitrite measurement processes
Process maps are made in order to explain the different routes and processes within the different production lines. Two different types of waste are observed in these processes:

1. Waste of time
2. Waste of nitrite salt

Theoretical perspective
By using the theory of Lean, the following indicators are defined:

Waste of time

1. Taking a sample.
2. Walking to the analyzer.
3. Preparation for inserting the sample into the analyzer and inserting the sample.
4. Walking back to the production process.
5. Reading the result and write it down on paper.

Waste of nitrite salt

1. Waste of nitrite by sampling for nitrite concentration measurements.
2. Waste of nitrite salt by the scrapping of pallets.

Efficiency of the nitrite measurement system
This chapter is removed due to confidentiality.

Methods of nitrite analysis and analyzers available on the market
A literature study is conducted in order to define the different methods of nitrite measurement. Here, a method of nitrite analysis is identified which is capable of measuring the nitrite concentration in-line. This method is called near infrared analysis (NIR). Thereafter, different analyzers are identified which are available on the market. Two NIR analyzers scored the best according to a criteria list with the following criteria: analysis time, accurate results, price of the analyser and the degree of difficulty for the usage of the analyzer.

Tests
This chapter is removed due to confidentiality.

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TERMS AND DEFINITIONS

Process optimization method: the discipline of adjusting a process so as to optimize some specified set of parameters without violating some constraint.

Problem cluster: a cluster which shows an overview of all the problems observed in a company.

External validity: the data's ability to be generalized across persons, settings, and times.

Internal validity: the ability of a research instrument to measure what it is purposed to measure.

Content validity: the extent to which it provides adequate coverage of the constructs guiding the study.

Criterion-related validity: the degree to which the predictor is adequate in capturing the relevant aspects of the criterion.

Construct validity: the degree to which you operationalize your variables properly.

BPR: business process re-engineering which is a process optimization method.

TQM: total quality management which is a process optimization method.

SAP: one of the largest enterprise resources planning software system.

Waste: anything that does not add value to produce the product or service.

Value: how the specific product meets the customer's needs, at a specific price, at a specific time.

Flow: the uninterrupted movement of product or service through the system to the customer.

R^2: a statistical measure of how well the regression predictions approximate the real data points.

1. INTRODUCTION

In this chapter is first explained what AkzoNobel is and in which markets it is active in. Thereafter, the process of nitrite measurement is explained whereas the problems which are observed by AkzoNobel in this process. Subsequently, the restrictions of this research are given. Finally, the research questions will be stated and for each research question the data gathering method is explained.

1.1 COMPANY INTRODUCTION

AkzoNobel is a paints and coatings company and major producer of specialty chemicals. Headquartered in Amsterdam, the company has activities in more than 80 countries, and employs approximately 45,000 people. AkzoNobel's employees are active in four main markets: industrial, consumer goods, transportation, and buildings and infrastructure [1].

- *Industrial:* AkzoNobel is one of the leading suppliers to the worldwide industrial sector. AkzoNobel supplies essential ingredients such as metals and mining, agrochemicals, plastics and pulp that help their customers to manufacture their products as efficiently, sustainably and cost-effectively as possible.

- *Consumer goods:* AkzoNobel works closely with their customers in order to develop effective solutions and protection for their own products by providing coatings.

- *Transportation:* AkzoNobel is in this market focused on the supply of manufacturers and operators with advanced coatings systems that play an essential role in the global transportation sector.

- *Buildings and infrastructure*: AkzoNobel is a total solution supplier in this market. AkzoNobel provides essential products for the global construction industry, for example coil coatings, wood coatings and protective coatings.

AkzoNobel is active in three businesses, Decorative Paints, Performance Coatings and Specialty Chemicals.

- *Decorative Paints:* the business Decorative Paints is focused on the development of products to color and protect both the inside and outside of all kinds of buildings – from private homes to office buildings.

- *Performance Coatings*: the business Performance Coatings is focused on the production of coatings which are used by customers across the world to protect and enhance everything, for example wood coatings, marine coatings, and metal coatings.

- *Specialty Chemicals:* the business Specialty Chemicals are used in paints, detergents, foods, plastics, cosmetics, construction, pulp and paper, pharmaceuticals, electronics, agriculture and for producing petroleum products. This bachelor report is written in collaboration with AkzoNobel Hengelo. AkzoNobel Hengelo is one of the production locations of AkzoNobel where salt products are produced. AkzoNobel Hengelo belongs to the Specialty chemicals group [2].

1.2 THE PRODUCTION PROCESS

This chapter is removed due to confidentiality.

1.3 IDENTIFICATION OF THE PROBLEM

After a specific amount of nitrite salt is produced, a sample is taken from one package by an operator and this sample is brought to one of two analyzers. The function of the analyzers is to analyze the concentration of nitrite of this specific sample. This package where the sample is taken from is always thrown away. Therefore, a lot of nitrite salt waste arises from this activity. Besides this physical waste, a lot of activities are involved for taking a sample. This process is very time consuming. These two types of waste are calculated in chapter 3 Efficiency of the nitrite measurement system, this chapter is removed due to confidentiality.

Problem cluster
A problem cluster is a cluster which shows an overview of all the problems observed in a company. This problem cluster is made when looking specifically at the process of nitrite measurement which is shown in Figure 1: Schematic representation of the problem cluster. However, it could be that the problem is not the measurement itself; instead, the variety in the dosage of nitrite could be the main problem.

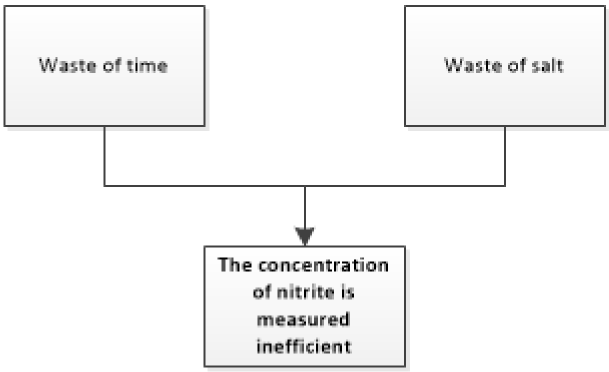

FIGURE 1: SCHEMATIC REPRESENTATION OF THE PROBLEM CLUSTER

Variety in nitrite dosage
The dosage of nitrite is not accurate at the moment, because the nitrite is stuck at places beyond the movement direction of the dosing screw according to the process technologist of AkzoNobel Hengelo [3]. Therefore, a part of nitrite is not added and this will lead to an inaccurate dosage of nitrite. Factors that could play a role here are the type/driving of the dosing screw and the humidity of the salt. However, this is not part of my research since this research is only focused on the process of nitrite measurement.

Core problem & action problem
The core problem is the main problem observed by AkzoNobel. The core problem is defined as: “There is an inefficient system for the measurement of the concentration of nitrite”. The action problem is an observed discrepancy between the norm and reality. As is shown in the problem cluster, in reality, there is waste of time and nitrite salt. These types of waste need to be reduced; however the norm is not known yet. This will be explained in chapter 2.4 Inefficiency at AkzoNobel, this chapter is removed due to confidentiality. With this information, the action problem is defined as: “The waste of nitrite salt and the waste of time should be decreased in the process of nitrite measurement”.

1.4 RESEARCH QUESTIONS

The research questions which will be answered in this bachelor report are defined in this chapter. The following research questions are based on the problem that is observed by AkzoNobel.

The main research question is: "How can the efficiency of the process of measuring the concentration of nitrite be improved?"

In order to answer this question, several sub-questions will be answered:

1. What is the definition of efficiency?
2. How can the inefficiency of the current nitrite measurement system be measured?
   2.1 Which theories can be applied to measure inefficiency?
   2.2 Which theory will be used in this research and why?
   2.3 How can inefficiency be measured at AkzoNobel?
3. What is the inefficiency of the current nitrite measurement system?
4. Which method of nitrite measurement is the best suited for AkzoNobel?
5. How can the efficiency of the current nitrite measurement system be improved?
   5.1 Which analyzers for measuring nitrite concentration are already available on the market?
   5.2 Which analyzer is the best suited for AkzoNobel?

1.5 RESTRICITIONS

The restrictions of this research are as follows:

- The research is conducted in a limited time period of ten weeks.
- The research focuses on the measurement of nitrite salt. Other problems such as the variety in the nitrite dosage are not in the scope of this research.
- AkzoNobel demands an analyzer that is capable of analyzing in-line. With in-line is meant that the analyzer is implemented inside the process and the process is analyzed continuous. In addition, a sample is taken automatically.

1.6 DATA GATHERING METHOD & DATA VALIDATION

In this subchapter, the data gathering method and the method how the validity of the measurements is ensured per research question are described. The data gathering method is the method of how the data is collected for a particular research question. Data validity is according to Cooper et al., (2014) [4] the extent to which a test measures what it actually wished to measure. There are two major forms of validity: external and internal validity. External validity is the data's ability to be generalized across persons, settings and times whereas internal validity is the ability of a research instrument to measure what it is purposed to measure.

External validity is not involved in this research since the conclusions of this research will not be generalized among persons, settings and times.

According to Cooper et al., (2014) [4] internal validity consists of three major forms:

- Content validity: the extent to which it provides adequate coverage of the constructs/instruments guiding the study. It is not necessary with all research questions to have content validity since no instruments are used in this research.
- Criterion-related validity: the degree to which the predictor is adequate in capturing the relevant aspects of the criterion. This form of validity is simply achieved by explaining the predictions that are made in this bachelor report. In addition, the predictions should be based on facts.
- Construct validity: the degree to which you operationalize your variables properly. Construct validity is only related to research question 2. Here, it is important to operationalize the variables "waste of nitrite salt" and "waste of time" in all different forms of waste that will eliminated when an in-line nitrite measurement system will be implemented.

The data gathering method per research question is described below.

Research question 1: what is the definition of efficiency?
Simply, searching in different dictionaries will be the data gathering method in order to find the definition of efficiency.

Research question 2: how can the inefficiency of the current nitrite measurement system be measured?
A literature study will be conducted in order to find different theories about the measurement of inefficiency. Here, the purposes and framework of the theories will be explained. Afterwards, a theory will be chosen which is in accordance to the perspective of AkzoNobel. Finally, the indicators of the variables "waste of nitrite salt" and "waste of time" can be identified with the use of this theory.

Research question 3: what is the inefficiency of the current nitrite measurement system?
The indicators which are defined by the previous research question need to be calculated. This will be done by analysis and aggregation of data which is extracted from the computer systems at AkzoNobel.

Research question 4: which method of nitrite measurement is the best suited for AkzoNobel?
A literature study will be conducted in order to identify the different methods for measuring a particular nitrite concentration. Subsequently, the best nitrite measurement method will be chosen that is capable of measuring the nitrite concentration in-line.

Research question 5: how can the efficiency of the current nitrite measurement system be improved?
Firstly, all the different analyzers which are available on the market need to be identified. This is done by contacting all companies that provide nitrite measurement systems in The Netherlands. Secondly, the best suited analyzer need to be chosen according to a criteria list which describes the most important criteria for choosing an analyzer according to AkzoNobel Hengelo. Finally, this analyzer will be tested in order to conclude if this analyzer can be implemented at the process of nitrite measurement.

2. THEORETICAL PERSPECTIVE

In this chapter, firstly, a definition of efficiency will be given. Secondly, theories which are available in literature for measuring the efficiency of a process will be described. Thirdly, one theory will be chosen which is in accordance with the aim of this research. Finally, this information will be used to identify the indicators of the current nitrite measurement system.

2.1 DEFINITION OF EFFICIENCY

In this subchapter, research question 1 is answered: "What is the definition of efficiency?"

Efficiency is according to Collins dictionary [5]: "the quality of being able to do a task successfully, without wasting time or energy".
Efficiency is according to Cambridge dictionary [6]: "the good use of time and energy in a way that does not produce waste".
Efficiency is according to Oxford dictionary [7]: "achieving maximum productivity with minimum wasted effort or waste".

So, a system is efficient when it minimizes waste or effort, while maximizing productivity.

The most common goals of process optimization methods are minimizing cost, maximizing throughput, and/or efficiency [8]. The goal of this research is to improve the efficiency of the process of nitrite measurement at AkzoNobel Hengelo. The next section will therefore describe the process optimization methods which are available in literature.

2.2 PROCESS OPTIMIZATION METHODS

In this subchapter, research question 2.1 is answered: "Which theories can be applied to measure inefficiency?"

There are five common process optimization methods available which are Business Process Re-engineering (BPR), Lean, Kaizen, Six Sigma and Total Quality Management (TQM) [8] [9] [10].

BPR: according to Tonchia S. (2004) [11] BPR is focused on the restructuring of the business from a strategic viewpoint. This process optimization method will lead to radical change of the business processes and involves taking risks in the presence of big opportunities.

Lean: according to Nave D. (2002) [12] Lean is focused on the removal of all forms of waste. The application of Lean is done by 5 steps: identify value, identify value stream, flow, pull and perfection. Identifying the value stream is done by identifying the activities which add value. This sequence of activities is called the value stream. The third step involves the improvement of flow. The inhibitors of flow need to be avoided which are work in queue, batch processing and transportation. The main point of the fourth step, pull, is that the process only starts when the customer needs it. Finally, perfection is a repeated and constant attempt which focuses on the removal of nonvalue adding activities, improve flow and satisfy customer delivery needs.

Kaizen: according to the Cosima project of the lifelong learning program [8] Kaizen is focused on the gradual improvement of processes and on the development of people so that they are able to solve the problems and the desired results can be achieved.

Six Sigma: according to Nave D. (2002) [12] Six Sigma is focused on reduction of variation. This involves a methodology which includes five steps: define, measure, analyze, improve and control. Firstly, practitioners begin by defining the process. Secondly, the process will be measured and analyzed. Thirdly, solutions are developed and on this basis changes are made to the process. Finally, the process is controlled if the process is relatively stable and runs at a desired level. This is done in order to assure that no unexpected changes can occur.

TQM: according to Nave D. (2002) [12] TQM is defined as "a continuously evolving management system consisting of values, methodologies and tools, the aim of which is to increase external and internal customer satisfaction with a reduced amount of resources". TQM is a structured approach to organizational management that seeks to improve the quality of products and services [8].

2.3 LEAN

In this subchapter, research question 2.2 is answered: "Which theory will be used in this research and why?"

As shown in Figure 1: Schematic representation of the problem cluster, the waste of nitrite salt and the waste of time are the main causes of the inefficient nitrite measurement. The new nitrite measurement system needs to minimize these different forms of waste. As already is defined by Nave D. (2002) [12] Lean is focused on the removal of all forms of waste. The other process optimization methods are focused on other concepts, such as quality or restructuring of the business. Lean is therefore the process optimization method that fits the best with our goal.

What does Lean mean?
According to Gauci J. (2010) [14] Lean is defined as "a philosophical way of working which emphasizes the removal of waste within a process. Core to this philosophy involves the principle that expenditure of resources for any goal other than the creation of value for the end customer is wasteful and therefore should be a target for elimination. This principle is applied from the perspective of the customer who consumes a product or service." According to Nave D. (2002) [12] Lean is defined as "a systematic approach to identifying and eliminating waste through continuous improvement flowing the product at the pull of the customer in pursuit of perfection".

The Lean philosophy
Three key issues are defined by the Lean philosophy [15]:

- *The involvement of everyone:* the aim of Lean philosophy is to provide guidelines which embrace everyone and every process in the organization.

- *Continuous improvement:* Lean objectives are often expressed as ideals, such as the definition given by Slack et al., (2010) [15] to meet demand instantaneously with perfect quality and no waste. "While any operation's current performance may be far removed from such ideals, a fundamental Lean belief is that it is possible to get closer to them over time. This is why the concept of continuous improvement is such an important part of the Lean philosophy".

- *The different types of waste according to Lean:* seven types of waste are defined which form the core of Lean philosophy [15] [16]:

1. Over-production: producing more than immediately is needed by the following operation.
2. Waiting time/other waste of time: time that is not effectively used.
3. Transport: moving items or raw materials around the operation does not add value.
4. Process: the process itself may be a source of waste. Some operations exist because of poor design or maintenance which could be eliminated.
5. Inventory: holding inventory does not add value.
6. Motion: unnecessary movement of machineries and operators.
7. Defectives: waste of product.

2.4 INEFFICIENCY AT AKZONOBEL

This chapter is removed due to confidentiality.

3. EFFICIENCY OF THE NITRITE MEASUREMENT SYSTEM

This chapter is removed due to confidentiality.

4. METHODS OF NITRITE ANALYSIS

This chapter is removed due to confidentiality.

4.1 METHOD OF NITRITE MEASUREMENT OF CURRENT ANALYZERS

This chapter is removed due to confidentiality.

4.2 METHODS OF NITRITE MEASUREMENT: A LITERATURE STUDY

According to Strother T. (2009) [18] raw material identification is one of the most important quality control aspects in the chemical manufacturing. Identifying materials quickly and reliably before they are used in the process will help ensure that the final product meets specifications and reduces costs associated with wasted materials and time. Traditional chromatographic or wet chemistry techniques are the opposite of raw material identification. These techniques identify materials with the usage of liquids. Unfortunately, these techniques require considerable time, technical training and destroy the sample in the process. Ideally, a method of raw material identification would be rapid, easy to perform and non-destructive. These requirements are met by spectroscopic techniques. These techniques involve the interactions of light with materials. In addition, spectroscopy is much more rapid than chromatographic and wet chemical methods and can provide proper identification in less than two minutes.

Three common forms of raw material identification by spectroscopy are: Near-infrared (NIR), Mid-infrared (MIR) and Raman spectroscopy [19] [20] [21].

MIR is not able to measure the nitrite concentration in-line. Therefore, this method is not applicable in this research [22]. Other techniques of raw material identification by spectroscopy will be discussed below.

NIR

According to Metrohm (2013) [22] NIR spectroscopy is a simple, quick (<30s analysis time), non-destructive technique that provides analysis with levels of accuracy and precision that are comparable to UV spectroscopy. NIR analyzers require no sample preparation or manipulation with chemicals, solvents, or reagents. NIR absorption spectra are often complex, this spectra is influenced by the chemical, physical, and structural properties of all species present in a sample. NIR models describe how the measured absorption values of samples (measured at many different wavelengths) are related to properties of the analysed material (for example the concentration of the sample). This principle is shown below in Figure 2: Principle of NIR.

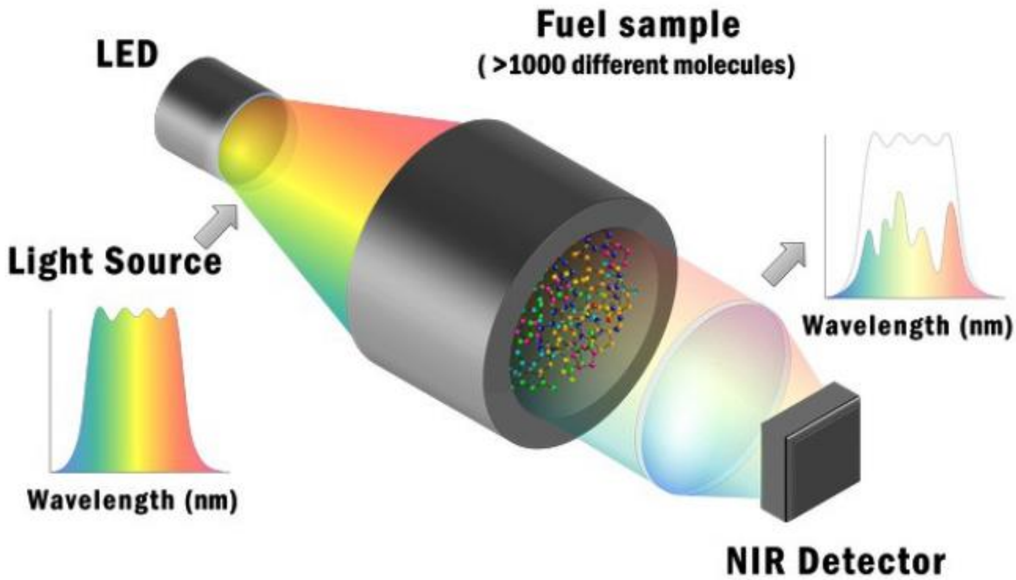

FIGURE 2: PRINCIPLE OF NIR

Raman

According to Strother T. (2009) [18] Raman spectroscopy relies strictly on the non-elastic scattering of photons from a laser source. When the photons from the laser interact with the material, a few are absorbed. The remaining energy is re-emitted as scattered light at a different frequency. The scattered light is shifted from the original laser frequency by an amount that depends on the energy absorbed by the molecular bonds. When the light encounters molecules in the sample, they can interact in such a way that energy can be either lost or gained by the scattered photons. The energy difference between the incident photon and the scattered photon can be detected and transformed into a visual representation of the data gathered. This principle is shown in Figure 3: Principle of Raman.

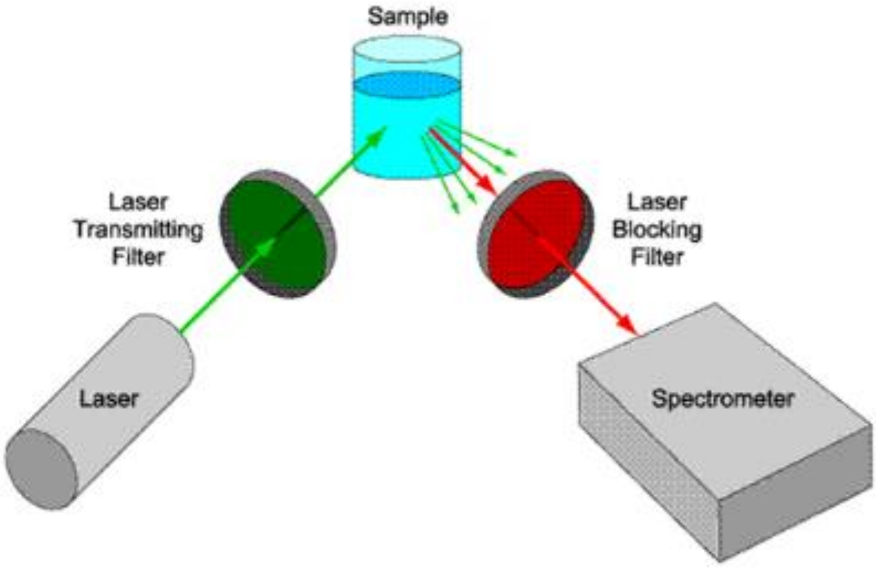

FIGURE 3: PRINCIPLE OF RAMAN

Conclusion
According to Metrohm (2013) [22] NIR is the most flexible technique in comparison with Raman and MIR. NIR analysis allows the determination of multiple values in a single determination. In addition, NIR is ideally suited for quality control of raw materials. NIR is better suited for analyzing powder mixtures like nitrite salt in comparison with Raman [18], see Figure 4: Differences between NIR and Raman. In conclusion, NIR is the best suited method for AkzoNobel Hengelo.

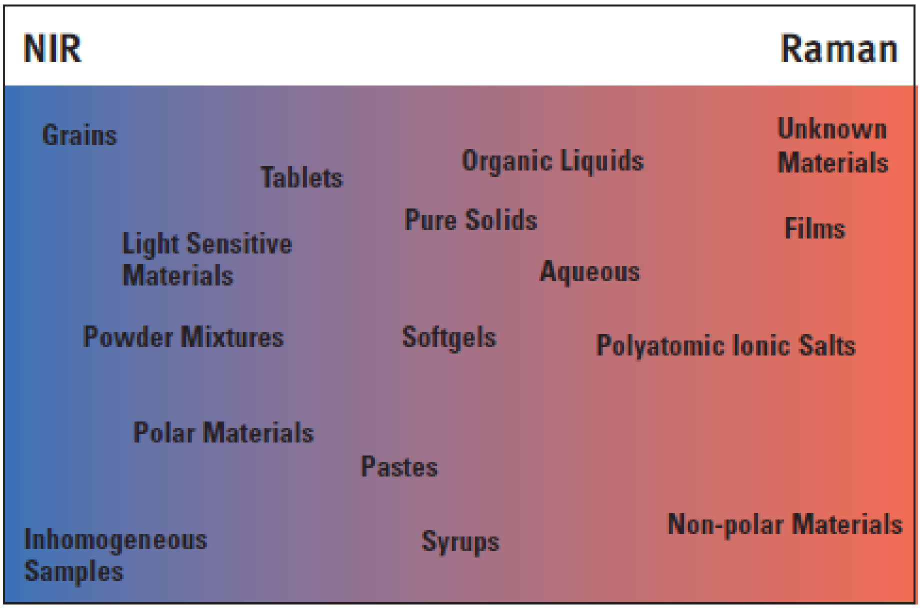

FIGURE 4: DIFFERENCES BETWEEN NIR AND RAMAN

5. ANALYZERS AVAILABLE ON THE MARKET

Chapters 5 t/m 7 are involved with answering research question 5: “How can the efficiency of the current nitrite measurement system be improved? “

In this chapter, a criteria list is made in order to evaluate the analyzers which are available on the market. After that, the analyzers that use the NIR technique are identified. In addition, analyzers that use other techniques that measure the concentration nitrite in salt are identified. This is done in order to begin as general as possible. At the end of this chapter, the different analyzers are evaluated according to the criteria list and finally the best suited analyzer for AkzoNobel Hengelo will be chosen.

The first criterion which is not shown in the criteria list of Table 1: Criteria list with weights is whether the analyzer is resistant in a salty environment. The analyzer can simply not be implemented if it is not designed for usage in a salty environment. This criterion is therefore not scored since the companies that offer these analyzers are not contacted.

There are four approaches to weight and criteria generation [23]. In this research, the “expert panel” approach is used because the criteria and weights should be in accordance with the demand of AkzoNobel Hengelo. This approach uses the opinions of experts in order to generate weights and criteria. This is done by a brainstorm session with the experts of the technology department of AkzoNobel Hengelo. The results are shown in Table 1: Criteria list with weights.

Criteria list			
Criterion	Weight	Variable	Units
1. Analysis time	0.35	Time	Min
2. The analyzer gives accurate results	0.35	R^2	%
3. Price of the analyzer	0.15	Price	Euro
4. Difficulty for the usage of the analyzer.	0.15	Degree of difficulty	Difficulty 1 Difficulty 2 Difficulty 3

TABLE 1: CRITERIA LIST WITH WEIGHTS

The criteria are evaluated per analyzer as follows:

- Analysis time: the lead time for analyzing a nitrite salt sample. The analysis time influences waste of nitrite salt by the scrapping of pallets. When the analysis time of the analyzer is as small as possible, it will lead to a faster detection of a nitrite salt package that is outside the customer specification. As a consequence, fewer packages with this nitrite salt that is outside the customer specification are thrown away.
- The analyzer gives accurate results: the first step to investigate and quantify the agreement between measurements made by two methods is to plot the data according to Bartlett et al., (2008) [24]. The simplest plot is of subjects’ measurements from the NIR method against another measurement method. If both measurements are completely free from error, the points lie on a diagonal line of equality with a R^2 of 1. This means that the results of both methods are exactly the same. The degree of this equality is shown by R^2 which is statistical measure of how well the regression predictions approximate the real data points. However, this criterion can only be scored after tests. The results of these tests are explained in chapter 7 Tests, this chapter is removed due to confidentiality.
- Price of the analyzer: this criterion means simply the price of the analyzer including all other costs such as transportation costs, taxes, costs of usage etc.

- Difficulty for the usage of the analyzer: this criterion means the degree of difficulty to use the analyzer for the operators. This degree of difficulty is dependent on whether the analyzer is connected to a software system and/or the nitrite concentration is saved automatically. Therefore, three degrees of difficulty are defined:

    1. Difficulty 1: the analyzer is connected to a software system which visualizes the nitrite concentration in green/red zones. In addition, the analyzer is capable of saving the nitrite concentration automatically.
    2. Difficulty 2: the analyzer is connected to a software system which visualizes the nitrite concentration in green/red zones. The analyzer is not capable of saving the nitrite concentration automatically.
    3. Difficulty 3: the analyzer is not connected to a software system. The nitrite concentration results need to be written by hand.

The typical method for project-ranking purposes is the Goal Achievement Matrix (GAM) [23]. With this method, it is possible for all investment alternatives to rank these alternatives systematically and unambiguously. This method places all criteria used for evaluation into a matrix form. The matrix entries are the normalized scores assigned to each alternative of each criterion. The weights are also specified. Finally, the product of the score matrix and the vector of weights produces a weighted score matrix.

Dutch companies are only contacted because communication with people of other countries is not optimal and it might lead to more delay. The nitrite analyzers of these companies are resistant in a salty environment and are evaluated in Table 2: Criteria list with scores.

Criteria list				
Criterion	Weight	Company X	Company Y	Company Z
1. Analysis time	0.35	10 min	1 min	1 min
2. The analyzer gives accurate results	0.35	Can not be determined yet	Can not be determined yet	Can not be determined yet
3. Price of the analyzer	0.15	50k euro	95k euro	100k euro
4. Difficulty for the usage of the analyzer.	0.15	Difficulty 3	Difficulty 1	Difficulty 1

TABLE 2: CRITERIA LIST WITH SCORES

Normalization is done as follows: divide each row by the value of the best score and then multiply the result by 100. However, when the best score is the lowest value as by the criterion “analysis time”, the lowest score becomes the numerator, that is, every other score is divided into that value and the result is multiplied by 100. For example, the best score on the criterion “analysis time” is 1 min. So, the normalized score of Company X on the criterion analysis time is equal to: $\frac{1}{10} * 100 = 10$. The results are shown in Table 3: Criteria list with normalized scores.

Criteria list				
Criterion	Weight	Company X	Company Y	Company Z
1. Analysis time	0.35	10	100	100
2. The analyzer gives accurate results	0.35	Can not be determined yet	Can not be determined yet	Can not be determined yet
3. Price of the analyzer	0.15	100	53	50
4. Difficulty for the usage of the analyzer.	0.15	33	100	100

TABLE 3: CRITERIA LIST WITH NORMALIZED SCORES

The weighted score matrix is shown below in Table 4: The weighted score matrix.

Criteria list				
Criterion	Weight	Company X	Company Y	Company Z
1. Analysis time	0.35	3.5	35	35
2. The analyzer gives accurate results	0.35	Can not be determined yet	Can not be determined yet	Can not be determined yet
3. Price of the analyzer	0.15	15	7.95	7.5
4. Difficulty for the usage of the analyzer.	0.15	4.95	15	15
Total	1.0	23.45	57.95	57.50

TABLE 4: THE WEIGHTED SCORE MATRIX

Conclusion
The weighted score matrix shows that the analyzers provided by Company Y and Company Z scored the best according to the criteria. The difference between the scores of these analyzers is equal to $57.95 - 57.5 = 0.45$. This means that both analyzers scored approximately the same according to the weighted score matrix. Therefore, both analyzers will be tested in the next section in order to identify the scores on the accuracy criterion.

6. FEASIBILITY STUDY

This chapter is removed due to confidentiality.

7. TESTS

This chapter is removed due to confidentiality.

8. CONCLUSIONS AND RECOMMENDATIONS

This chapter is removed due to confidentiality.

REFERENCES

[1] Site of AkzoNobel. Accessed at: 28-03-2018. Link: https://www.akzonobel.com/

[2] Internal document of AkzoNobel Hengelo with all general information about AkzoNobel Hengelo

[3] Conversation with X (process technologist of AkzoNobel Hengelo) at 29-03-2018

[4] Cooper, D. R., & Schindler, P. S. (2014): Business Research Methods

[5] Efficiency. (n.d.). *In Collins dictionary online.* Accessed at 19-04-2018. Link: https://www.collinsdictionary.com/dictionary/english/efficiency

[6] Efficiency. (n.d.). *In Cambridge dictionary online.* Accessed at 19-04-2018. Link: https://dictionary.cambridge.org/dictionary/english/efficiency

[7] Efficiency. (n.d.). *In Oxford dictionary online.* Accessed at 19-04-2018. Link: https://en.oxforddictionaries.com/definition/efficient

[8] The Cosima project of the lifelong learning program

[9] Ajaz M. (2015): *Wait a minute! What is the difference?*

[10] Does R.J.M.M. (2015): *Lean Six Sigma*

[11] Tonchia S. (2004): *Fundamentals of Process Management and Business Process Reengineering*

[12] Nave D. (2002): *How to compare Six Sigma, Lean and the Theory of Constraint*

[13] Andersson R., Eriksson H. & Torstensson (2006): *Similarities and differences between TQM, six sigma and Lean*

[14] Gauci J. (2010): *What is Lean?*

[15] Slack N., Chambers S. & Johnston R. (2010): *Operations management*

[16] Khalil A. El-Namrouty, Mohammed S. AbuShaaban (2013): *Seven Wastes Elimination Targeted by Lean Manufacturing*

[17] This reference is removed due to confidentiality

[18] Strother T. (2009): *NIR and Raman: complementary techniques for raw material identification*

[19] Doyle W.M. (2001): *Comparison of near-IR and Raman analysis*

[20] Sorak D., Herberholz L., Iwascek S., Altinpinar S., Pfeifer F., Siesler H.W (2013): *New Developments and Applications of Handheld Raman, Mid- Infrared, and Near-Infrared Spectrometers*

[21] Site of Bruker online. Accessed at: 24-05-2018. Link: https://www.bruker.com/applications/pharma-biopharma/quality-assurance/pat1.html

[22] Metrohm (2013): *NIR spectroscopy*

[23] Berechman J. (2009): *The evaluation of transportation investment projects*

[24] Bartlett J.W., Frost C. (2008): *Reliability, repeatability and reproducibility: analysis of measurement errors in continuous variables*

[25] Conversation with X (process technologist of AkzoNobel Hengelo) at 20-06-2018

[26] Conversation with X (process technologist of AkzoNobel Hengelo) at 23-05-2018

[27] Conversation with X (financial employee of AkzoNobel Hengelo) at 25-05-2018

APPENDIX

This chapter is removed due to confidentiality.