# Bachelor Thesis Industrial Engineering & Management

Improving the automated dosing system of an industrial food production company

Public summary

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UNIVERSITY OF TWENTE.

# Improving the automated dosing system of Company X

Bachelor Thesis in Industrial Engineering and Management


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# Preface

In front of you lies a Public summary of my bachelor thesis: “Improving the automated dosing system of Company X”. With this Thesis, I will finalize my bachelor's program in Industrial Engineering and Management at the University of Twente. I conducted this thesis at Company X, where I carried out my research from April to July 2022.

During the process of writing this thesis, I was greatly supported by all the employees at Company X. The topic on which I did my research was quite new to me so I needed the help and knowledge of other employees at Company X. Based on the help and great working environment I would like to thank all employees at Company X who helped me in completing the thesis.

More specifically at Company X, I would like to give a special thanks to my company supervisor for all the time he put into helping with my thesis. His help when I had any questions and his feedback during the entire period greatly helped me in the execution of this thesis.

Finally, I would like to thank my university supervisor, Dr. Gayane Sedrakyan, for all the advice, support, and feedback I received over the course of my bachelor thesis. I would also like to thank my second supervisor Dr. Lucas Meertens, for the great feedback and support during the final weeks of my thesis.

I hope you enjoy reading my thesis!

Timo Looms

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# Management Summary

According to a newly developed methodology for improving existing systems, Company X should change their automated dosing system in several ways to improve performance. These are changes to the existing automated dosing system as well as changes about improving the automated dosing system for future, new implementations of the system.

The goal of this research, conducted at Company X, was to find ways in which Company X could improve their automated dosing system. The automated dosing system is a system, which enables the automatic addition of raw materials to the production process

To achieve this goal, ahead of the research a methodology was developed to make sure the research would be conducted systematically. A summary of the general working of the methodology is the following. Firstly, the system should extensively be analyzed: functions, KPIs, flowcharts, current performance, and current problems should all be described. Next, literature research is done to find improvements and alternatives to current processes and (sub) components/ (sub) systems. After this, the possible decisions for the system are listed and tested to the extent possible within the scope of this research. Finally, recommendations are made.

Based on the research Company X should in short term make several changes to the automated dosing system. These changes would improve performance on the established KPIs, and would therefore improve the performance of the system.

For the future implementation of the system, Company X should follow established policies on key decisions for installing a new dosing system on other production lines. These policies support Company X in the most important decision-making steps. However, are excluded from this Public summary.

Based on the literature this research also established options, which Company X should further analyze, to find the viability of these solutions for the situation at company X. From the literature, we namely retrieved that these options could improve performance on the KPIs.

This research not only gave points of improvement for Company X but also proved the newly developed methodology is an excellent tool for improving an existing system

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# Chapter 1: Assignment description

## 1.1. The automated dosing process

This research is conducted at an industrial food production company which due to confidentiality will be called Company X.

The process, which should be improved, is the addition of raw materials in the production process. For a few production lines at the location, this process of adding premix has been automated by a system, which is called an “automated dosing system”. This is a system consisting of storage locations for the raw materials, weighing bunkers to dose components accurately, and a pneumatic transport system. An automated dosing system has been developed and implemented with an external partner, which we will call Company Y.

My research should help the company with the implementation of the automated dosing system for the other production lines. My task is to give recommendations for the implementation of the automated dosing system for the other production lines. For example, which (sub) processes should be in the process. Which (sub) systems/components should be in the system? Is the improved system worth it to implement? Furthermore, my task is also to advise the company on improvements to the current system. How can the performance of the system, which is currently in use be improved?

## 1.2. Problem description

All problems in the problem description are related specifically to the production lines for which the system still needs to be added, as the automated dosing system has already been implemented in the other production lines at the location.

### 1.2.1. Inventory of problems

- *Manual labor for adding raw material*
- *Buying in bulk is not possible*
- *High raw material costs*
- *Low traceability*
- *Packaging waste of raw materials*
- *Operators over occupied at times*
- *Not enough time for cleaning the production line*
- *Malfunctions*
- *Operators cannot solve malfunctions quick enough*
- *Downtime*
- *Low efficiency*
- *Low hygiene*
- *Low accuracy*
- *No possibility to adjust recipes by quality service*
- *Lower quality end product*

### 1.2.2. Problem cluster and Core problem

For the problem cluster of the manual process, see Appendix A: problem cluster

The only problem in the problem cluster without a cause is the problem “Premix needs to be added manually by the operator”. Therefore, based on information from Heerkens & van Winden (2017) the core problem is that “Premix needs to be added manually by operator”.

# Chapter 2 Research Methodology

## 2.1. Problem-solving approach

The in chapter 1 mentioned core problem used to be a core problem for the other production lines as well, however for these production lines the core problem has already been solved. An automated dosing system for the addition of premix and other resources has been implemented to reduce the amount of manual labor needed. Therefore, the assignment is to find out what can be learned about the implementation of the automated dosing system for the other production lines. And how the solution should be implemented in the other production lines. Therefore, the global approach to solve this problem is to use the basis of the current automated dosing system as a solution but create an improved design to solve this problem. Below there are some necessary steps in my research.

### 2.1.1. Do

- Make a flowchart of the current dosing system in use.
- Identify main processes and sub-processes from the flowchart.
- Create a questionnaire/interview for more information on improvements in the automated dosing system.
- Make a list of improvements/problems of the dosing system based on feedback from several departments.
- List all options for components and decisions, and list their functions.
- Set up KPIs to determine the performance of several components.
- Retrieve data for the KPIs.
- Write advice on how to improve the current system.
- Write a piece of advice for the implementation of the automated dosing system on other production lines.

### 2.1.2. Discover

- Exploratory research into the components and decisions for the automated dosing system
- Exploratory research into the working of the system and points of improvement based on old correspondence.
- Exploratory research into points of improvement based on feedback from several departments.
- Exploratory literature research establishes certain conditions necessary for the system to work. For example external conditions and raw material conditions.
- Exploratory literature research to see if other options exist to perform functions performed by current systems.
- Descriptive research into the relationships between decisions to be made and the KPIs.
- Explanatory research into the performance of components/ (sub) systems on the KPIs.

### 2.1.3. Decide

- Which components should be included in the advice for the new dosing system and which not? These decisions are based on feedback, KPIs, etc.
- What should the process of the new dosing system look like?
- What changes to make to improve the dosing system currently in use?

### 2.1.4. MPSM steps

The seven steps of the Managerial Problem-Solving Method (MPSM) are used to structure how the core problem will be solved. (Heerkens & van Winden, 2017)

1. Defining the problem
   See problem description
2. Formulating the approach
   Steps listed in the do/discover/decide steps
3. Analyzing the problem
   Analyze the current situation: Set up a flowchart of the current automated dosing system of production lines. Identify the main and sub-processes. Get more information on the feedback of several departments at the company (questionnaire/interview). Set up KPIs. Establish the influence of the components/subsystems/processes on the KPIs.
4. Formulating (alternative solutions)
   Formulate solutions to the core problem; the solutions would be automated dosing system decisions to consider for solving the core problem. The solutions would be a flowchart of the process to choose from and a list of components/subsystems to make decisions on for the process.
   Also, formulate possible solutions for problems in the current automated dosing system in use right now.
5. Choosing a solution
   Based on KPIs a decision will be made on which of the listed dosing systems would perform the best.
   Based on KPIs decisions will be made for the listed solutions for the system currently in use
6. Implementing the solution
   Step not done in my research, as my result will be advice on how Company X will implement the solutions; therefore the actual implementation will not be included in the research.
7. Evaluating the solution
   Evaluate how the performance of the current automated dosing system would improve with the suggested solutions to problems. And evaluate how well the dosing system would work on the other production lines with the suggested design. Write advice based on this, so the company can go ahead with the implementation if it is performance is as desired.
   (Heerkens & van Winden, 2017)

## 2.2. The research

### 2.2.1. Research goal

The goal of the research is to find how the solution currently in use for the core problem can be improved for the other production lines, so Company X can implement the improved solution in the remaining production lines and therefore solve the core problem there as well. Improvements will be measured by the KPIs, which are to be established during the research. Company X already knows what the solution is to the core problem (the automated dosing system), however, lacks the information on how this solution can be optimized before implementation. This is explanatory research, which in the end will give an improved solution to the core problem.

**Main research question**: How can the performance of the automated dosing system of Company X be improved in accordance to the established KPIs for the implementation of the other production lines?

To answer this research question, a combination of several research methodologies are used: Data gathering by performing reliable and valid interviews/questionnaires (Cooper & Schindler, 2012) and (Systematic) Literature Research. Data analysis by data mining (Mathew, Abraham, & Kalayathankal,

2018) and/or process mining (Aguirre & Parra, 2017). Process visualization is done using Business Process Model and Notation (BPMN) 2.0 (Object Management Group, 2011).

### 2.2.2. Knowledge problems/research questions

1. What are the main conditions necessary for the automated dosing system to work properly? Some example conditions could be: temperature of the raw materials, desired accuracy of the resources dosed, etc. (exploratory research)
2. Which KPIs are relevant when considering the performance of the automated dosing system of Company X? Knowledge problem in step 3 of the MPSM analyzing the problem, more specifically: setting up KPIs step. The KPIs established in this step are used as a tool to track performance, measure the needs for improvement and measure the improvement of the system at the end. (exploratory research)
3. What are some main differences to consider between the production lines, which affect the desired automated dosing system? Knowledge problem in step 3 of the MPSM analyzing the problem. Will help with adjusting the solution for the other production lines (exploratory research)
4. What are the main points of improvement concerning the automated dosing system according to several departments at company X? Knowledge problem in step 3 of the MPSM analyzing the problem, more specifically: Get more information on the feedback of several departments at the company step. (exploratory research)
5. Systematic Literature Review (SLR) problem: Which other design options exist to perform the function of component/subsystem X? Find alternative solutions for design decisions. SLR knowledge problem with component/subsystem X being the silo design currently in use. (exploratory research)
6. To what extent is there a relationship between component/subsystem/ (sub) process X and KPI Y? To measure the performance of each component/subsystem/ (sub) process the relationship between the component/subsystem/ (sub) process on the KPIs needs to be determined. This is done in step 3 of the MPSM by analyzing the problem, more specifically: Establishing the influence of the components/subsystems/ (sub) processes on the KPIs. (descriptive research)
7. What is the relevance of each KPI regarding the performance of the entire automated dosing system? Necessary in step 5 of the MPSM choosing a solution, there will probably be trade-offs: one solution would perform better concerning KPI X but worse on KPI Y. So to make a decision on which solution to implement a ranking of the relevance of the KPIs is necessary. (descriptive research)
8. Systematic Literature Review (SLR) problem: What characteristics does the raw material need to be used in the automated dosing system? There needs to be established that the raw materials of other production lines are applicable for the automated dosing system. My supervisor at the company already informed me about some characteristics (free-flowing and total solid powders) which now are still quite unknown to me. (Exploratory research)

### 2.2.3. Theory

To provide an answer to the main research question, this is split into two parts. First, research the weighted relevance of KPIs on the performance of the entire system; secondly, research what the relationship is between the decisions for system design and the KPIs.

Key construct one (KC1) shows the relationship between the KPIs and the performance of the entire system the variables are KPI (independent variable), the relevance of KPI on the entire system (moderating variable), and the performance of the entire system (dependent variable). This construct is used to determine the relevance of each KPI for the entire system, and how much performance in one aspect influence the working of the entire system.

Key construct two (KC2) shows the relationships between the design decisions and the KPIs. The following variables are included:

- Independent variable (IV): design decisions, these will be changed to optimize the system. For example, decisions about components/subsystem/processes.
- Dependent variable (DV): the KPI, as this is what will be measured to establish how the design decisions influence performance.
- Moderating variables (MV): raw materials and production line, which affect the relationship, for example, some raw materials might flow through the system better/worse and some production lines are located closer to the warehouse than others (both factors can influence the relationship between the design decision and the KPI).
- Control variables (CV): the conditions in the factory and the employee at the production line; these might influence the dependent variable but are not at the core of the research.

When combining the two constructs KPI becomes an intervening variable and there is a relationship between the design decisions and the performance of the entire system.

For the conceptual models, see Appendix B: conceptual models

### 2.2.4. Research design

To answer the main research question: How can the performance of the automated dosing system of Company X be improved for the implementation of the final two production lines? A combination of explanatory and descriptive research is necessary. All knowledge problems as stated earlier need to be answered so all relationships as described in the conceptual model(s) are known.

The first research questions to answer are the research questions, which establish the conditions necessary for the automated dosing system to work, concerning the raw materials but also the system. This will be explanatory research with the research population of the company, but also scientific sources. The methodologies used for data gathering will be interviews and literature research. Based on this a list of conditions for the raw materials and dosing system is made. Answering these questions would give us an idea of whether the dosing system would be relevant for the other production lines as well.

For KC1 (Appendix B) the relationship between KPIs and the performance of the system the following research questions need to be answered: “Which KPIs are relevant when considering the performance of the automated dosing system of Company X?” and “What is the relevance of each KPI concerning the performance of the entire automated dosing system?”. The research population for this would be the stakeholders as they establish the goals, but also data will be retrieved from the database as based on this can be determined which KPIs are important and how important they are. The main research method used will be performing reliable and valid interviews for data collection. The variables in this part are the KPIs to be established and the performance of the entire system.

For KC2 (Appendix B) the final research questions need to be answered: “What are some main differences to consider between the production lines which affect the desired automated dosing system?” for the MV production line and the considerations about the design decisions. “What are the main points of improvement about the automated dosing system according to several departments at company X?” And “Which other design options exist to perform the function of component/subsystem X?” To determine design options for the IV design decisions. Finally “To what extent is there a relationship between component/subsystem/ (sub) process X and KPI Y?” to determine what the relationship between the design decisions and the KPIs is. To answer these three research questions interviews and/or questionnaires again need to be performed. Furthermore to establish the relationship between components/subsystems and KPIs literature research will be performed to get a general idea of these relationships. Data/Process mining methods are used to specify the exact relationships between the decisions and KPIs for the situation at Company X.

Based on this the main research question is answered as everything necessary is known at this point to determine how the performance of the automated dosing system can be improved.

# Chapter 3: Context analysis

In the context analysis, the current situation for the production process concerning the addition of raw materials will be discussed. A clear distinction is made between the automated dosing process and the manual process for the production lines where the system still needs to be implemented.

Furthermore, in the context analysis, KPIs and their relevance are determined and a baseline measurement is performed on these KPIs. With this baseline measurement, we establish the performance of the current automated dosing system and the performance of the manual process (only on the KPIs applicable).

Finally, some problems with the current system are established through interviews. And the key differences between the production lines are determined.

## 3.1. Process and system description

Within the process and system description for both the old manual process and the automated dosing system, a BPMN model was used to illustrate the process flows. Furthermore, all components and their functions were described for both processes. Due to confidentiality, these are excluded from this confidential version.

## 3.2. KPIs

This research uses Key Performance Indicators (KPIs) as the main tool to inspect the current performance of the automated dosing system, evaluate possible decisions and measure future performance and progress of the system. Therefore establishing KPIs of sufficient quality for both tracking and analyzing performance as well as evaluating improvement at the end is an essential step within our research. In this part of the report in the first instance, the KPIs are selected and afterward, the relevance of each KPI on the performance of the entire system will be established.

### 3.2.1. KPI development

To determine the KPIs the following knowledge problem will be answered: "Which KPIs are relevant when considering the performance of the automated dosing system of Company X?" To solve this, I need interviews with the relevant experts on the system and/or stakeholder(s) needs to be conducted. Also exploring the data available will be necessary.

Furthermore, the KPIs will be established following the criteria of Nolan & Anderson (2015). More specifically this means that when setting up the KPIs they have to be aligned with organizational goals and clearly defined without being ambiguous. The interviews give assurance that the KPIs below are in line with the goals of Company X for the automated dosing system. KPIs are clearly defined as well as they are KPIs specifically in line with the function of the automated dosing system, making them very specific and not ambiguous.

#### *Interview development*

For developing KPIs, semi-structured interviews are performed (Cooper & Schindler, 2012). This means that the questions are fixed in advance, however, the order and number of questions can be altered depending on the interview. Furthermore, a semi-structured interview offers the option to ask additional questions when needed. Both a structured and unstructured interview has something to offer in setting up KPIs. Unstructured would help for getting an idea of what possible performance could be relevant, whereas structured could help to find the exact importance of each KPI on the performance of the entire system. This is why it is best to combine the best of both worlds using a semi-structured interview.

### *Findings*

The final KPIs determined based on the semi-structured interviews are the following.

*The accuracy of dosing components*

This is measured by the deviation of the weight of the raw material from the amount requested. This is an important indicator as inaccurate dosing of components leads to lower product quality and possible waste of raw materials.

*The speed of dosing components*

At all times company X should prevent the dosing process influences the production speed, therefore the speed needs to be above a certain threshold to prevent it from being a bottleneck. Right now the amount of raw materials which can be dosed at the same time is limited, to make sure the speed is reached.

*Time until return on investment (ROI Time)*

The best way to measure the financial benefits of the automated dosing system would be to estimate the time until a return on investment (so the amount of time until cash flow savings generated by the project equal the investment).

*Product quality:*

By using the automated dosing system, the process of producing the product changes, and therefore keeping a high product quality is important. An external party determines this product quality periodically.

### 3.2.2. Relevance of each KPI

To achieve recommendations for Company X on design decisions in the automated dosing system the relevance of the KPIs must be established. This way for example when a trade-off takes place, so a decision has a positive influence on one KPI but a negative influence on another KPI we can still make a recommendation. For this, we need to answer the knowledge problem: "What is the relevance of each KPI concerning the performance of the entire automated dosing system?"

Based on the interviews conducted, product quality is the most important KPI but this also depends on the accuracy of the system. The ranking concerning KPIs from most to least important would be Product quality, accuracy at IBC, speed, and finally ROI Time. The flowchart illustrates the relationships KPIs have with each other and how this relates to the performance of the entire system.

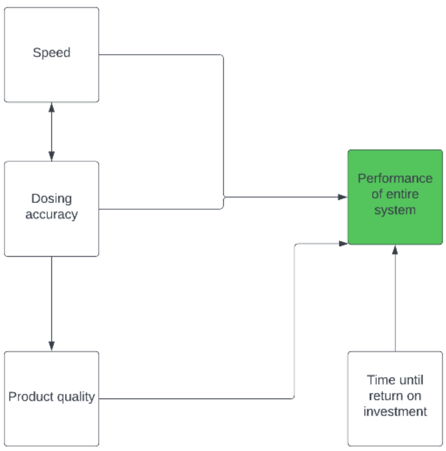


*Figure 1: KPI relationships*

### 3.2.3. Drivers of KPIs

Establishing direct links between performance indicators and value drivers is essential for both process-modeling and value-modeling perspectives. (Rosing, Foldager, Hove, von Scheel, & Bøgebjerg, 2015), therefore it is important to establish some of the value drivers of the given performance indicators.

Change in the accuracy of the dosing process is driven mainly by change in the dosing process, meaning that the accuracy of the process can be improved by changing certain components of the system for more accurate dosing.

Changing the dosing speed is mostly driven by the speed required, if the speed required is achieved increasing the dosing speed is pointless as this could negatively influence accuracy. Furthermore, change in dosing speed is driven by the number of big bag sections: more section means more components, which can be dosed at the same time increasing speed.

Product quality is driven by the accuracy of the dosing process, having more accurate dosing means the Product quality would be better.

The time until the return of investment is driven by the initial investment of the system and the raw material cost savings because of the system.

## 3.3. Baseline measurement

For each KPI the current performance is assessed for the current automated dosing system in place. For the baseline measurement of the manual process a numerical value could not be assessed for the KPIs as the KPIs are established for the automated dosing system and even though they might be relevant, these are not measurable for the manual process. However, for this, a general description of the performance was given.

Due to confidentiality, the baseline measurement results on the KPIs are excluded from this Public summary.

## 3.4. Problems with the current system

### 3.4.1. Interview development

To find problems/feedback of the system the people whom we should question using a questionnaire or interview are the following. One experienced person per relevant department who has worked for Company X both before and after the implementation of the automated dosing system. Preferably, these people would also be people who worked on the development of the automated dosing system. Furthermore, it would also be relevant to question one or some of the operators who worked with both the manual system as well as the new automated system.

My supervisor recommended me to use interviews instead of a questionnaire, as this would achieve more reliable/valid answers. This is more time-consuming but as this step is very important in the research, we conducted interviews.

To find the problems of the current system again we conducted semi-structured interviews (Cooper & Schindler, 2012).

The questions for the interview with the employees from each department are focused on the problems and points of improvement from the perspective of their departments. Furthermore, some issues in the several phases before and after implementation are discussed.

For the interviews with the operators, the goal is to find points of improvement for the current system and considerations for the other production lines from the people working with the system. In addition, the system is evaluated in comparison to the old manual system from their perspective.

### 3.4.2. Problems

Based on the interviews conducted, some problems were established with the automated dosing system. These were some very specific problems for a certain product or certain raw materials, but also some general problems of the automated dosing system.

The found problems give an idea of what can be solved in the current system and what needs to be solved for a new system. Due to confidentiality, the problems are excluded from this version.

## 3.5 Differences between production lines

Here are some differences and similarities between the production lines for which the system has already been installed and the production lines where the system still needs to be installed are established.

This helps with considering how the system needs to be adjusted to the other production lines, from the system Company X knows right now.

# Chapter 4: Literature research

The goal of this literature research is both to find more theoretical information on the process this thesis researches and to find alternatives to current (sub) systems. Within this chapter, the goal is to answer the following two knowledge problems: "What are the main conditions necessary for the automated dosing system to work properly?" and "Which other design options exist to perform the function of component/subsystem X?" Furthermore, this chapter also establishes measurement options for the characteristics of the raw materials.

## 4.1. Establishing conditions

### 4.1.1. Raw materials

To establish the conditions of the raw materials following knowledge problem we need to answer the following knowledge problem: "What characteristics does the raw material need to be used in the automated dosing system?" For this, appendix C shows the systematic literature review performed which resulted in the following findings:

Sub question 1: *What are the characteristics necessary for the raw material to be stored in a Silo and discharged from a Silo?*

For discharge from the silo, the flow properties are required to be free-flowing which means it has to have a flow ability coefficient of above 10. Dependent on the gap width of the discharge opening the flow ability coefficient may need to be higher, but with the current system, the flow ability does not need to be higher than 10 (Mellmann, Hoffmann, & Fürll, 2014). The general formula for the flow ability coefficient is (consolidation strength) / (compression strength). Furthermore, the flow properties of the raw material within the silo are influenced by the particle size distribution of the raw material as this leads to more cohesive behavior (Fürll & Hoffmann, 2013). The mean particle size, and median/modal form factor (ratio of particle length to width) have been determined to influence the flow ability (Mellmann, Hoffmann, & Fürll, 2014) smaller particle size and form factor mean a higher flow ability. Therefore, to determine whether the component has the characteristics/properties for efficient discharge from the Silos either Company X should measure the consolidation strength and compression strength to determine the flow ability coefficient. Alternatively, using the particle size and form factor an estimation can be made for the flow ability coefficient. (Rooda, 1975) (Lanzerstorfer, 2020)

*Sub question 2: What are the characteristics necessary for the raw material to be transported through vacuum tubes?*

The raw material needs to be free-flowing again for the vacuum transport, the tubes are 65 mm and therefore again the free-flowing coefficient should be higher than 10 (Mellmann, Hoffmann, & Fürll, 2014).

Furthermore, for the raw material to be transported through the vacuum tubes the pressure minimum curve should be known, based on this the (negative) pressure of the system can be determined. (Pan, Mi, & Wypych, 1994) For this several characteristics of the raw material affect it, the Froude number at pick up point, which is an important characteristic of powder flow can be determined by the formula in figure 2 (Pan, Mi, & Wypych, 1994). Having a lower Froude number means the material is transported with less (negative) pressure needed. Therefore, the characteristics of the raw materials influencing vacuum transport efficiency are the following: product flow rate to air mass flow rate and bulk density. Lower bulk density and lower product-to-air mass flow rate would give a more efficient vacuum transport. (Mošorinski, Prvulović, & Palinkaš, 2017)

*Conclusion of sub-questions:*
The necessities of the raw materials for the automated dosing system are to be powder, which is free-flowing (free-flowing coefficient > 10). This can be estimated by using the consolidation strength and compression strength (instruments to measure this exist) or estimating using particle

*Figure 2: Froude formula (Pan, Mi, & Wypych, 1994)*

size and form factor. Furthermore, the components should have very low humidity and low bulk density for high flow ability.

### 4.1.2. Other conditions

To establish other conditions necessary for the system to work properly the following knowledge problem needs to be answered: *What are other conditions necessary for the automated dosing system to work properly?* Per my company supervisor some things to consider are temperature (warehouse temperature, production department temperature, and raw material temperature), amounts to dose, and tolerance. Furthermore, the literature review establishes conditions for such a system to work.

This report only discusses the main findings from literature as the knowhow of Company X on the conditions needed is confidential.

For the vacuum transport tubes, the main conditions are the power supplied by the vacuum pump is enough to transport the materials over the given distance within the desired time. Tube material should be able to withstand the abrasiveness of the material. (Bhatia) (Mills, 2004)

Concerning the weighing bunkers, the bunkers need to be clear of external forces during the weighing process as the accuracy will be low due to unreliable measures if this is not the case.

## 4.2. Other design options and considerations for existing components

For several components/subsystems, this part establishes alternative design options to be considered within the research. Through literature for each of these components/subsystems, this part answers the following knowledge problem: “Which other design options exist to perform the function of component/subsystem X?”

### 4.2.1. Silos and big bag hoppers

To establish the design considerations about the currently in use silos and hoppers the following knowledge problem needs to be answered: “Which other design options exist to perform the function of the silos/hoppers currently in use for the automated dosing system?” This systematic literature review has been performed (see appendix C) which gives the following findings:

First, the difference between a silo and a hopper needs to be established, a Silo is mostly used for long-term storage. A silo sometimes uses a hopper for letting out the raw material at the bottom of the silo a hopper can also be used for storage separately, sometimes in combination with a big bag.

Considering the main functions of a silo it is relatively simple, a Silo should store bulk materials, but a silo should also have sufficient solids outflow. The second is one of the main challenges of a silo as the materials can get stuck in many ways, for example bridging (an arch of powder forms blocking outward flow) or rat holing (flow only goes through the middle with a large amount of powder on the sides). The main challenge therefore with bulk storage is to achieve good powder flow. (Schwedes, 2001) (Tüzün & Nedderman, 1982) (D’Arco, Donsì, Ferrari, Montesano, & Poletto, 2006)

One of the key decisions is the flow type within the silo, the options for this are funnel flow (material in the middle flows down first) or mass flow (all materials flow at the same time). (D’Arco, Donsì, Ferrari, Montesano, & Poletto, 2006)

There are six main hopper geometries to help the silo/hopper achieve sufficient powder flow: transition hopper, chisel hopper, wedge hopper with converging end walls, non-symmetric pyramid asymmetric cone, and multiple hoppers. (Carson & Craig, 2015). Therefore with the design of the silo, this is one of the key decisions to consider, is a hopper needed? If so which geometry to use?

Another option in the design process of silos/hoppers is to support the silo outflow, for example with vibration to increase the discharge rate. (Du, Liu, Wang, Ding, & Wang, 2020)

To prevent dust accumulation on the walls of silos and hoppers there exist several discharge aids/cleaning methods that could solve dust accumulation on the walls of silos, hoppers, or IBCs. For example acoustic cleaning systems, fluidizing pads, knockers, or cone valves. (Brûlé, Plant, & Bartholomew, 2011)

Of course, there are also some general design decisions like volume, width, height, material, and wall roughness to consider. (Carson J. W., 2001) (Carson & Craig, 2015)

*Conclusion:* Design options for bulk storage are very broad but some key decisions to consider are:

- Do we use a silo or a (big bag) hopper for storage?
- If we use a silo, do we also use a hopper to achieve better outflow?
- Do we support silo/hopper outflow? If so how?
- Finally, what are the other characteristics of the Silo/ (big bag) hopper? Volume? Width? Height? Materials? Wall roughness? All these questions need to be answered based on the needs and conditions of the company when installing a new storage location.

### 4.2.2. Transport system

For transporting bulk solids there are two main options to do this, pneumatically through tubes either vacuum or pressure. Alternatively, mechanically conveying uses machinery to physically transport bulk solids, for example, screw conveyors or belt conveyors.

Using mechanical conveyors makes more sense when products cannot be transported through pneumatic conveying, for example, products that are too heavy, not free-flowing, or too moist. Therefore making mechanical conveying a viable option when the raw materials are not free-flowing or too moist. In most other instances, mechanical conveying is the less efficient option for powders and gives too high risk for dust explosions.

Concerning pneumatic conveying there are a few main decisions: firstly should be considered whether the conveying has to be a dilute phase, dense phase, or some flexible system consisting of both methods. With a dilute phase, there is a continuous airstream whereas a dense phase is essentially a batch process. (Bhatia). Dense phase would be better suitable for friable products or abrasive products, in most other instances dilute-phase conveying is the more efficient option. After this, there should still be considered whether vacuum (negative pressure), positive pressure or a combination of both should be used. (Bhatia). Furthermore, for dense phase systems also a dense phase method should be chosen from 7 options with each their benefits: fluidized, low-velocity slug, low-velocity plug, bypass conveying, single slug conveying, extrusion flow, or air-assisted gravity conveying.

After having determined the method of pneumatic transport some other key decisions are the following: Piping, the piping route should be as direct as possible with the least number of direction/elevation changes. Another aspect concerning piping is the type of material to use for the piping, currently, stainless steel is used, other options are aluminum or galvanized steel. Fan selection is also an important aspect to consider, this greatly depends on the power required which is based on the conveying distance and desired speed. Finally, it is important to determine how the material will be separated from the air stream; the most common methods for this are filters or cyclones.

To summarize key decisions:

- Mechanical or pneumatic, in this situation mechanical should only be considered if pneumatic is not possible due to material properties.
- If pneumatic: dilute phase or dense phase, in this situation only if the raw materials are very friable of abrasive dense phase should be considered.
- Vacuum/pressure / or combination, expectation vacuum due to multiple pick-up points per destination, and material leak containment.
- Pump selection is dependent on the power required to transport the required distance in the time necessary.
- Establish optimal piping route
- Tube material, stainless steel, aluminum, or galvanized steel
- How does the system separate raw materials from air stream: Filters, or other separation methods?

(Mills, 2004)

### 4.2.3. Weighing bunkers

To establish the design considerations about weighing bunkers this part answers the following knowledge problem: "Which other design options exist to perform the function of the weighing bunkers currently in use for the automated dosing system?"

The first type of weighing method by IBCs works in the following way: The raw materials are transported from a storage location toward the IBC. Load cells measure the weight of the raw material in the IBCs, by converting the downward pressure compared to an empty bunker. This weighing method is called a hopper weigher (Schwartz, 2000). If the amount weighed is too low more raw material is retrieved, after enough raw material is retrieved, the weighing process is terminated. This method weighs the amount of raw material intake at the receiving hopper, which is also called gain-in-weight dosing (Weighing & Batching systems - Powder Dosing explained ! Gain in Weight, Loss in Weight dosing systems, sd).

The alternative to this is loss-in-weight dosing which places the load cells on the hopper driving the dosing (Weighing & Batching systems - Powder Dosing explained ! Gain in Weight, Loss in Weight dosing systems, sd). The advantage of loss-in-weight dosing is that multiple ingredients can be dosed at the same time into the receiving hopper, however, it requires more load cells so higher costs and more possibilities concerning unreliable measures due to more measures.

Furthermore, the weighing bunkers need a component to separate the raw materials from the vacuum airstream. The most common method for this is using filters. An important consideration for these filters is whether to implement a de-dusting method and the material. Right now, the filters of Company X are equipped with a pulsejet de-dusting method, meaning that compressed air is pulsed out of the filters to unclog them from dust. Whether or not to use such a method depends on the raw material and how much powder build-up they cause without it. Concerning materials the two main options are plastics or fabrics, plastics are a bit stiffer making it more difficult for the system to shake off the powder build-up with the pulsejet meaning plastic filters could cause more powder build-up. (Filters for pneumatic conveying - Dedusting after pneumatic transport, sd)

To summarize key decisions:

- Choosing gain-in-weight dosing or loss-in-weight dosing. Loss-in-weight enables the dosing of multiple components at the same time, at the expense of being more expensive and giving a higher chance of inaccuracies.
- Is a filter de-dusting method needed, depending on raw materials and the amount of powder build-up caused by raw materials connected to the weighing bunker?
- Filters from plastic or fabrics depends on the amount of powder build-up and the raw materials connected to the weighing bunker.

### 4.2.4. Feeding methods in the dosing process

With this Literature research, the goal is to establish which feeding method is optimal for certain situations.

The following main methods are identified: Firstly blow through/drop through rotary airlock valves. This system works in the following way, the product drops into the holes of the valve, which is turned and then dropped into the vacuum pipe, where the product is then sucked into the vacuum tube. This way the product can be dosed based on the volume, which fits in one part of the rotor, so the rotor turns until the desired amount of volume powder (based on bulk density) has gone through the rotor. This is a way of volumetric dosing. The difference between a blow-through and drop-through rotary airlock valve is, that in a blow-through system the vacuum is directly connected to the rotor making the airflow go through the holes of the rotor (Rotary Airlock Valve - an Engineering guide (Design, Calculation), n.d.) (Mills, 2004)

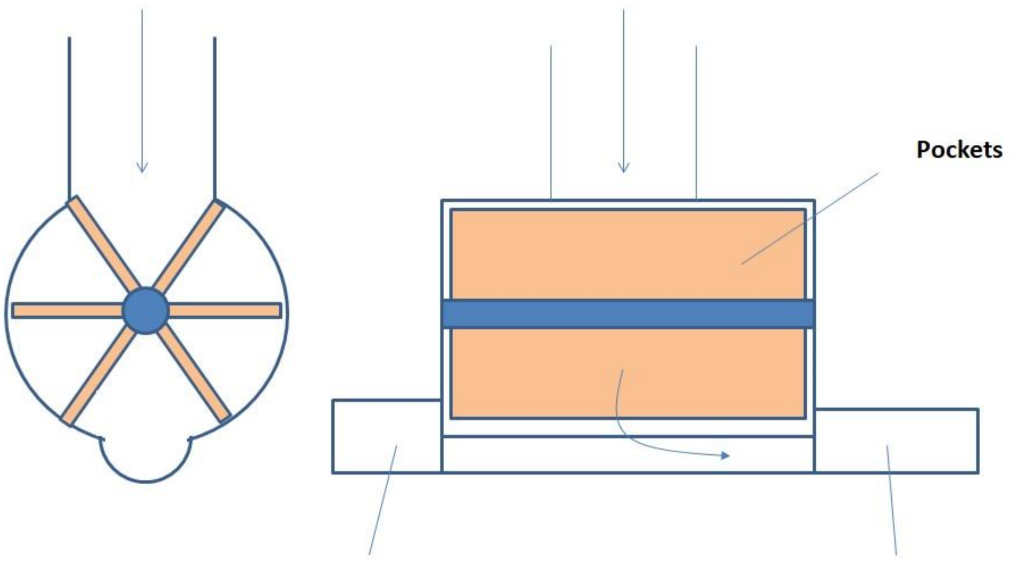


*Figure 3:Blow Through Rotary Airlock Valve (Rotary Airlock Valve - an Engineering guide (Design, Calculation), n.d.)*

Another option is to use screw feeders. This system moves the raw material horizontally through the pitches of a screw/auger. By rotating a screw flight or auger, the raw material moves mechanically through the system, the raw material is dosed based on the volume of raw materials, which fits into the pitches of the screw conveyors. Therefore, the screw turns until the desired volume of powder (based on the bulk density) has been fed through the conveyor by the flights. This is also volumetric dosing (Screw Conveyor Overview (Screw Feeder / Auger), n.d.) (Mills, 2004)

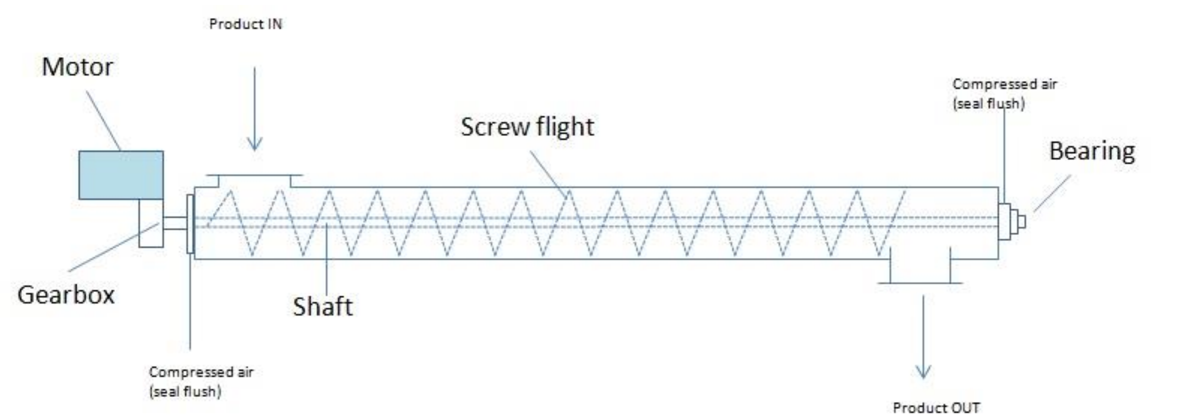


*Figure 4: Screw conveyor (Screw Conveyor Overview (Screw Feeder / Auger), n.d.)*

A common issue with screw feeders is that the raw material can turn into lumps when under pressure. A solution to this could be to change the screw feeding process in some way to prevent lumping or to change the feeding method to for example an airlock valve. When an airlock valve is used pressure on the raw material would be lower preventing lumping. Another option could be to use a twin-screw feeder, which should prevent lumping, as the product will be mixed through each other. Alternatively, use a mass flow screw feeder that is better suited for sluggish bulk materials. (Mount III, Wagner Jr., & Giles Jr., 2014) Finally adding an anti-caking agent to the raw material might also prevent lumping (Zafar, Calvert, Vivacqua, Ghadiri, & Cleaver, 2017).

## 4.3. Measurement of free-flowing characteristics of powders

To analyze the characteristics of the materials of Company X to support decision-making for the automated dosing system the properties of the raw material need to be measured. The powders, which are the only type of problematic raw materials when it comes to free-flowing characteristics, can be categorized in three phases:

Firstly static state where to powder(s) are piled and can be roughly compared to a solid, this would be the case for example in the silos/hoppers during storage. For measuring the properties of the raw material during the static phase, the GranuHeap method would be the measurement option. This method works based on how the heaps of powder formed are shaped; in general, if the angle of the heap is lower the flow ability would be better. This returns the static cohesive index, which would be close to 0 for a non-cohesive powder. (Lumay, et al., 2012)

Secondly, powders can be in a quasi-static state, which would mean the powders would rearrange themselves through slight vibration; an agitator or similar instruments can cause powders to move from static to quasi-static state. For this, the GranuPaq method would be a viable measurement option, this method works based on tapping the powder and the effect on the effect it has on the height of the sample. In the end, this method will return several useful characteristics, which are relevant to flow-ability during quasi-static state (Hausner Ratio/Carr index[1], Bulk density, and final density) (Lumay, et al., 2012)

Finally, powders can be in a dynamic state, in which they are flowing from one point to another, this would be the case during each form of transport of powders. Concerning the flowing properties, properties in the dynamic state would be the most important for the raw materials of Company X. These can be measured through the GranuDrum method; this method works based on analyzing the flow of the powder in a rotating drum and gives as a result of the flow ability and cohesion under certain circumstances. (Lumay, et al., 2012)

Ideally, all three measurements should be performed on the raw materials to get an understanding of how suited the system is for the raw materials to be dosed and added to the production process. This would support the decision-making process, however, as Company X does not have the tools available to perform these measurements this would for now be out of the scope of the research. However, could be a suggested step in future implementation.

Other options for this situation specifically are to test the free-flowing characteristics specifically for the current installation. For this, a test installation can be built or some components of the current installation can be used and test if the raw materials would flow through the system fast enough if they cause powder build-up, etc.

[1] Common measures used for flow ability on the basis of tapped and loose bulk density of raw materials

# Chapter 5: Solution design

It is already clear that the solution to the core problem of Company X is to implement the automated dosing system for the other production lines. Therefore, the solution design consists of the possibilities concerning the process flows and the possibilities about which components and subsystems to include in performing the dosing process. By doing this, important options and decisions for the design decisions as given in the conceptual models (see Appendix B) will be considered for the other production lines. Furthermore, this chapter discusses the solutions to problems, which have been found through literature. Within this chapter, only the decisions for which tests of academic level can be, performed using our methodology as described in chapter 2 were included.

The options are split into two parts, options to improve the current system and decisions for future implementation on other production lines. For the options of the current system, the most important methods to improve the performance of the current system are listed. These options should improve performance on KPIs by solving the problems, which were found during an earlier stage of the research.

Furthermore, for future implementation possible process flows are described through BPMN 2.0 models. From which a method needs to be chosen by Company X for the other production lines. For the components and subsystems, all possible components/subsystems for which decisions need to be made are listed separately.

The findings in this chapter are confidential and will therefore be excluded from this Public summary.

# Chapter 6: Solution tests

This chapter establishes the relationship between the design decisions and the KPIs as in the conceptual models in Appendix B. By doing so the knowledge problem: “To what extent is there a relationship between component/subsystem/ (sub) process X and KPI Y?” Will be answered for each decision and the KPIs. This would give us a clear idea of the trade-offs and benefits of each design decision concerning the KPIs and will help support the decision-making process concerning recommendations for Company X.

For each decision, the solution tests are structured in the following way. Firstly, the decision is briefly described with the possible options from which to choose and the method in which the decision is tested and data is retrieved. After this, each KPI is described to what extent, there is a relationship between the decision and this KPI. Finally, a table shows an overview of the relationships between the decision and the KPIs.

Relationships are established in two ways: Firstly, based on the data analysis, the data used for this will be of measurements performed at the company or historic data retrieved from the MES system. Secondly, the earlier performed literature research will be used as well as an indicator for possible relationships.

Intermediate recommendations were made based on these tests in which the solutions and advice give recommended decisions for company X.

# Chapter 7: Conclusions and recommendations

Within this chapter, the following research question is answered: “How can the performance of the automated dosing system of Company X be improved in accordance to the established KPIs for the implementation on other production lines?” Next to this research question, the following research question is also answered: “How can the performance of the currently in use automated dosing system be improved following the established KPIs?” In this manner both improvements to the current system will be made, as well as an improved system to implement in other production lines is created.

Also, this chapter discusses the reliability and validity of the research as well as its limitations of the research.

Finally, based on the conclusions and discussion, recommendations are made based on our research for both Company X and the general audience. From this further research is suggested.

## 7.1. Conclusions

For both of the two research questions mentioned, answers were found. Based on this, within this research, we were successfully able to find methods by which the performance of the automated dosing system can be improved. These are improvements about making changes to the current system, as well as improvements for the implementation of a new automated dosing system. From this, we can conclude that the developed methodology is a good method of improving an existing system, either by adjusting it or by more efficient implementation of an existing system. In the rest of the conclusion, the research questions are answered.

### “How can the performance of the currently in use automated dosing system be improved in accordance to the established KPIs?”

Concerning this question based on the problems with the current system, through brainstorming, literature search, and suggestions of colleagues, solutions were created to solve these problems. For some of the solutions, it was possible to analyze through measurements how these solutions would influence the KPIs and determine whether these would be worth the implementation. For some other solutions, this was not possible and solutions for further analysis are mentioned. Therefore, for each of the given problems, this is split into two parts: tested solutions and solutions to analyze

The findings by answering this research question are excluded because of confidentiality.

### “How can the performance of the automated dosing system of Company X be improved in accordance to the established KPIs for the implementation of the other production lines?”

To determine how the dosing system can be improved following the final two production lines. An overview of the most important decisions for these production lines is made, for each of these decisions a policy is made on how this decision should be made in accordance with the KPIs.

The findings by answering this research question are excluded because of confidentiality.

## 7.2. Discussion

Firstly, concerning our methodology at Company X, some of the possibilities to perform tests on a scientific level were limited with our methodology. One of the main reasons is that components/subsystems suggested improving performance were not available at Company X in short term, making it impossible to systematically establish relationships between these options and the KPIs. This issue was solved by only handling decisions, which to a certain degree could be measured within the solution tests, whereas further decisions retrieved from the research were included in the appendix.

Even in the measurements for some decisions, it was impossible to quantify how these decisions would influence KPIs. Especially the decisions about implementation on other production lines were more estimations rather than exact measurements. Or, are based on the situation at production lines where the system is currently in use. Measurements were mainly not possible as there is no automated dosing system to perform these tests on these other production lines. This problem was solved by creating policies in the recommendations and conclusions for further implementation, instead of exact advice on what Company X should include or not.

Reflecting on our KPIs, due to how the KPIs product quality and speed are measured it made it difficult to establish relationships between design decisions and these two KPIs. Product quality measures are only measured periodically, making it difficult to compare the influence of decisions on this KPI through tests as often no comparison is possible between the different situations as not a measure for both is available.
Concerning speed, an indicator was used to measure this. However, this indicator did not change in any situation, except for the decisions about storage locations for other production lines. Meaning this KPI has relatively poor validity, as some decisions should influence the speed.

Additionally, for some measurements generalizations had to be made to be able to make decisions. Results were generalized as it can be assumed that some decisions would have approximately the same influence on the KPIs in other similar situations. More of these generalizations were performed when the specific relationship could not be tested, but a relationship for a similar situation was already found. These generalizations are acceptable for Company X to a certain degree it can be assumed that these generalizations are correct meaning good recommendations could still be made based on this. However, these generalizations do influence the academic validity of the measures.

## 7.3. Recommendations for Company X

In this chapter, two types of recommendations are given based on the conclusions. Recommendations for the current system are made on how to improve performance on the established KPIs, and recommendations are made on how the system should be implemented for other production lines to achieve the best performance.

Each of these will again be split into two parts, recommendations that are based on what is currently available and known by Company X (the options for which tests were performed). These recommendations are retrieved from the intermediate recommendations of chapter 6: Solution tests. Secondly, we give recommendations that are expected to improve performance based on literature and brainstorming. However as these could not be tested these will be mentioned separately, and will be a suggestion to further analyze and test.

Due to confidentiality, both of these recommendations are excluded from this Public summary.

## 7.4. Contributions to literature

By comparing our findings to the literature researched, we can determine what gap in the literature was filled in by our research. A lot of the research is related to company X specifically meaning it does not add a lot to the literature currently known on topics discussed in this research. However, this research still achieved two main points to contribute to the literature: methodology of improving an existing system and KPIs for an automated dosing system

### 7.4.1. Methodology of improving an existing system

As concluded, the used methodology reached the goals needed within our research. The methodology used gave Improvements to the current system as well as improvements for future implementation. From which we concluded that our methodology is a good way of improving an existing system, either by adjusting it or by more efficient implementation of an existing system.

From this, we recommend that when tasked with improving an existing system either for adjusting the system or improving for implementation one should use the following methodology. These general steps could help structure research to improve an existing system.

*Methodology of improving an existing system*

- Analyze the system
  - Formulate the function(s) of the system
  - Establish KPIs to measure the performance of the system
  - Visualize the process executed by the system through flowcharts
  - Identify (sub)components and/or (sub)systems
  - Perform baseline measurement to assess the current performance of the system on the KPIs
  - Find problems with the current system through among others conducting interviews
- Literature research
  - Find solutions to existing problems
  - Find alternatives (sub)components and/or (sub)systems
- List possible decisions based on current knowledge of the company and literature research
  - List options about (sub)processes
  - List options about (sub) components and/or (sub)systems
  - List solutions to existing problems
- Test decisions
  - As far as possible perform tests to determine relationships between components and KPIs
  - Use literature research and knowledge at the company to determine relationships when tests are not possible
- Recommend how the company could improve the existing system by adjusting it, or improve the system for further implementation


*Figure 5: Methodology of improving an existing system*

### 7.4.2. KPIs for an automated dosing system

The KPIs used in the research proved to be an excellent tool for finding ways to improve the automated dosing system. Therefore, from these KPIs, some standard KPIs can be deducted to measure and track the performance of an automated dosing system. These KPIs would be the following:

- Accuracy of adding components in the desired quantity, measured by percentage deviation of the amount dosed from the amount required.

- Time until return on investment of the system, measured by the time until the cost savings associated with the system would equal the investment.
- Product quality for the product for which components are dosed, measured by QS employees or an external company.
- Dosing speed is measured by the production capacity available with the speed or the time it takes to dose one batch of components.

For our research, these KPIs adjusted to our specific situation were an excellent tool for improving an automated dosing system. Therefore, if someone needs to track the performance of an automated dosing system the suggested KPIs could be used as a basis.

## 7.5. Further research

This research not only discovered some ways in which Company X could improve their dosing system currently in use and for further implementation. This research also discovered a methodology for how to improve existing systems systematically. Further research will, therefore, be split into further research for Company X to perform based on my recommendations for them. As well as further research into the methodology developed.

### 7.5.1. Further research for Company X

For further research, Company X should focus on improving the automated dosing system even more by testing the options found in my literature search. When the tests of options result in improvements based on KPIs these options should be chosen for the current system and/or be included for further implementation.

Due to confidentiality, these options are excluded from the Public summary.

### 7.5.2. Further research on our methodology

For further confirmation of the methodology developed, more existing systems should be improved using our methodology. If the methodology would give good results within their research, this confirms that this methodology is a useful framework to implement for improving an existing system.

The focus should be on testing our methodology on systems with very different functions, or in very different industries. This would confirm that the methodology developed is not a specific methodology for this system or this industry.

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# Appendix

## Appendix A: Problem cluster

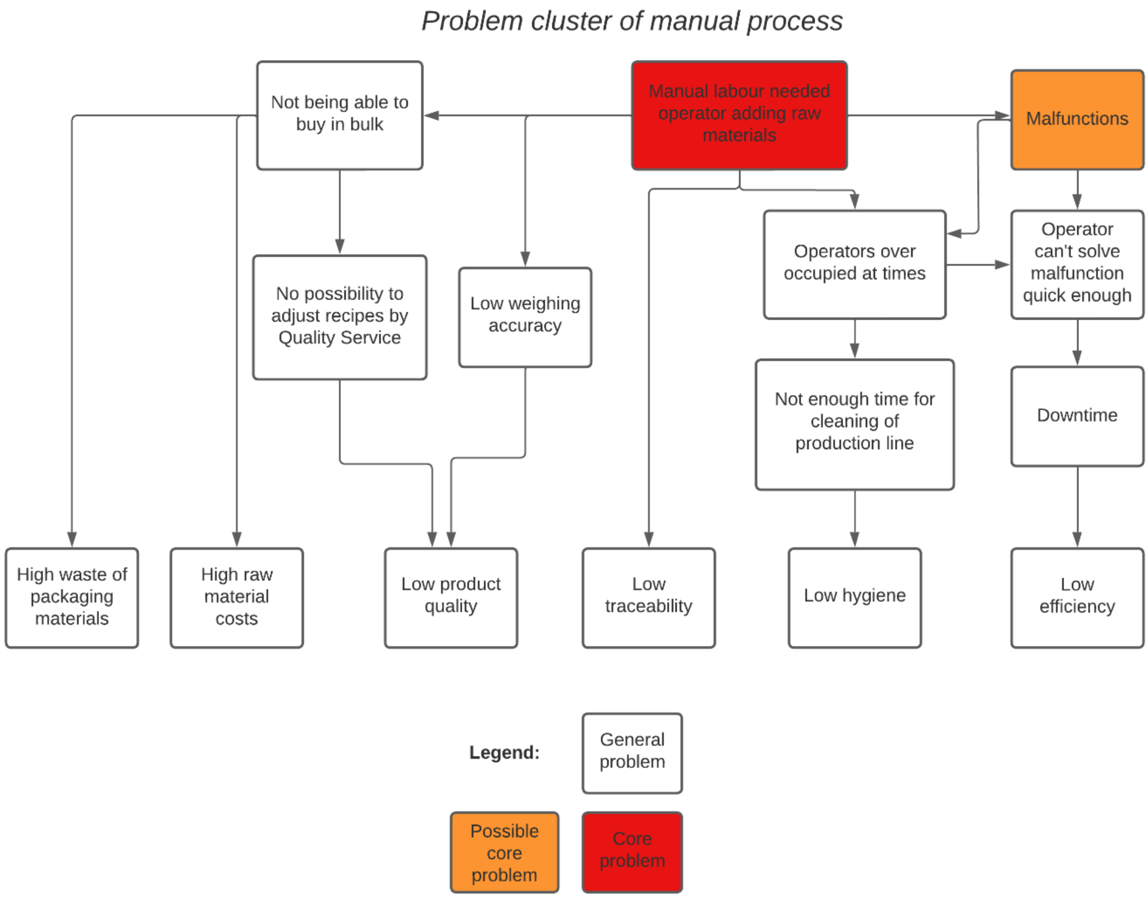


*Figure 6: Problem cluster*

# Appendix B: conceptual models

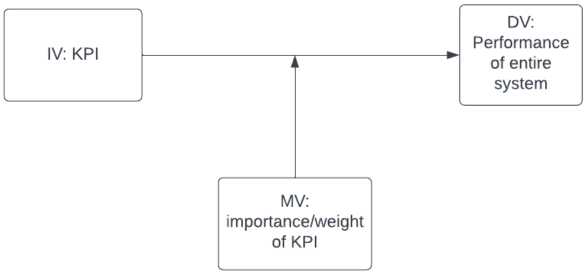


*Figure 8: Conceptual model KPI-Performance*

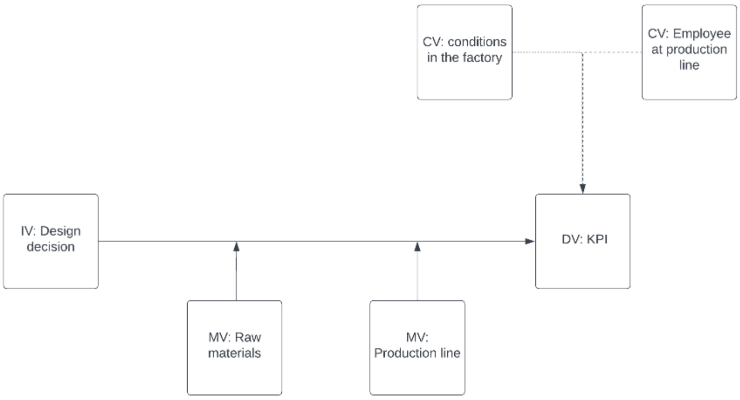


*Figure 7: Conceptual model design decision-KPI*

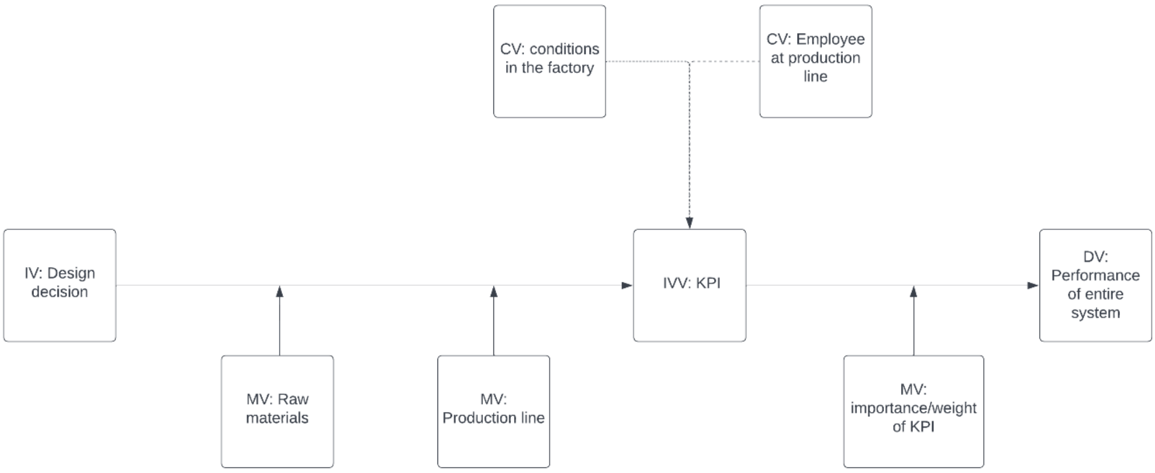


*Figure 9: Complete conceptual model*

# Appendix C: systematic literature review

## SLR 1: Silo design

Systematic literature review

For my systematic literature review I will be answering two knowledge problems “Which other design options exist to perform the function of component/subsystem X?” more specifically with component/subsystem X being the silo design Company X currently uses. And “What characteristics does the raw material need to be used in the automated dosing system?”

1. Which other design options exist to perform the function of the current Silo design in use at Company X? Some background information the function of a Silo is the storage of Bulk materials in this case some premix component, Company X is not looking for an alternative to Silos but rather a different Silo design which might be beneficial.

2. For inclusion/exclusion criteria the articles should have the following characteristics to be included:
   - Language: language should be English, Dutch, or German as these are understandable to me.
   - Availability: the article should be accessible through the University of Twente or have open access, so it can be read without costs.
   - Document type: for this SLR the document types accepted are (Journal) articles, papers, reviews, and books.

   A document will be excluded when:

   - It is subjective, for example, published by a company for their benefit

3. The design of a silo covers many disciplines: (industrial) engineering, chemistry, etc. therefore multidisciplinary databases will be the best option. *Web of Science* (a large database that covers more technical science), *Scopus* (a large multidisciplinary database more peer-reviewed), and *Science direct* (which covers especially science and technology well which is very relevant) will be the databases used in our SLR.

4. See table 1 for all the search terms, the strategy consists of a combination of the given search terms. Firstly, we will be using the following queries in our databases: Silo and design and options, Silo and design option. Dependent on the number of relevant results we will add related terms if more results are desired using the “or” operator, or we will use narrower terms instead of the key concepts if too many results are found. Furthermore, the most important terms (in this case Silo or related/broader/narrower terms) should be included in the title, if this gives few results this needs to be changed back to Title-Abs-Key.

| Key concepts | Related terms | Broader terms | Narrower terms |
|---|---|---|---|
| Silo | hopper | Bulk storage, bunker, (grain) bin | Industrial Silo |
| Design | System, concept | | Industrial design, |
| Options | Alternatives, solutions | | |

*Table 1: Search terms SLR 1*

5. Search log

| Date | Database | Query | #hits (relevant) | Retrieved articles |
|---|---|---|---|---|
| 17-3-2022 | Scopus | TITLE(silo) and TITLE-ABS-KEY( design and options) | 7 ( 2 sources relevant) | 1 after snowballing of unavailable article |
| 17-3-2022 | Web of Science | Topic(silo) and all fields( design and options) | 32 (+- 10% relevant) | 0 |
| 17-3-2022 | Web of Science | Title(silo or hopper) and all fields (design options or design solutions) | 2860 ( +-20 % relevant) | 1 (after refining results 34 hits out of which 1 retrieved article) |
| 17-3-2022 | Scopus | Title(Silo or Hopper or “grain bin”) And Title-abs-key(“Design options” or “Design solutions”) | 6 (3 of which are relevant) | 0 retrieved |
| 22-3-2022 | Sciencedirect | TITLE-ABS-KEY(Silo AND design AND options) | 11 (0 relevant) | 0 retrieved |
| 22-3-2022 | Sciencedirect | Title-ABS-key(Design) And Title(Silo) | 166(+-20% relevant) | 5 retrieved (2 directly + 3 through snowballing) |
| | | | | |

*Table 2: Search log SLR 1*

Sources from search 1:
(D’Arco, Donsì, Ferrari, Montesano, & Poletto, 2006)
From search 3:
(Du, Liu, Wang, Ding, & Wang, 2020)
From search 6:
(Rabinovich, Kalman, & Peterson, 2021) and (Carson & Craig, 2015)

Through snowballing: (Carson J. W., 2001), (Schwedes, 2001) and (Tüzün & Nedderman, 1982)

6. Concept matrix
   Theme: the design options of Silos
   The concepts have quite a lot of overlap therefore the concepts are marked which are most related to the articles.

| Article↓\concepts→ | Silo discharge | Powder flow | Silo design | Storage |
|---|---|---|---|---|
| (D'Arco, Donsì, Ferrari, Montesano, & Poletto, 2006) | | | | |
| (Du, Liu, Wang, Ding, & Wang, 2020) | | | | |
| (Rabinovich, Kalman, & Peterson, 2021) | | | | |
| (Carson & Craig, 2015) | | | | |
| (Carson J. W., 2001) | | | | |
| (Schwedes, 2001) | | | | |
| (Tüzün & Nedderman, 1982) | | | | |

*Table 3: Concept matrix SLR 1*

7. See thesis

## SLR 2: characteristics of raw materials

1. "What characteristics does the raw material need to be used in the automated dosing system?" Therefore, we need to find out what characteristics are necessary for storing the material in the silo and it from the Silo. And characteristics needed for good transport.

2. For inclusion/exclusion criteria the articles should have the following characteristics to be included:
   - Language: language should be English, Dutch, or German as these are understandable for me.
   - Availability: the article should be accessible through the University of Twente or have open access, so it can be read without costs.
   - Document type: for this SLR the document types accepted are (Journal) articles, papers, reviews, and books.

   A document will be excluded when:

   - It is subjective, for example, published by a company for their benefit

3. Again, like the decision of the systematic literature review for the silo both these sub-questions are multidisciplinary, for example, material properties (chemistry), (industrial) engineering, etc. Therefore, multidisciplinary databases would work the best again. This time only Scopus and Science direct as with these databases I had the best experience last time.

4. See tables 4 and 5 below for all the search terms, search strategy consists of searching for sources for both sub-knowledge problems separately. Other than this, a similar strategy as in SLR 1 is applied: do a basic search from the key concepts, and based on whether too few or too many results are obtained we will change up the search query. For example first search in title-abs-key (Vacuum And transport And raw material And characteristics) if too few results change Vacuum to Vacuum or suction, change raw material to raw material or research, etc. If too many results change Vacuum AND transport to in the title. This way we keep adjusting our search for each database.

   Sub question 1: What are the characteristics necessary for the raw material to be stored in a Silo and discharged from Silo?

| Key concept | Related terms | Broader terms | Narrower terms |
|---|---|---|---|
| Silo storage | Bin storage | Bulk storage<br>Silo | |
| Silo discharge | Silo unloading | Unloading<br>Conveying | |
| Characteristics | Properties | | |
| Raw material | Resource | | |

*Table 4: Search terms SLR 2 Q1*

   Sub question 2: What are the characteristics necessary for the raw material to be transported through vacuum tubes?

| Key concept | Related terms | Broader terms | Narrower terms |
|---|---|---|---|
| Vacuum | Suction | | |
| Transport | Conveying<br>Moving | | Tube transport,<br>pneumatic conveying |
| Raw material | Resource | | |
| Characteristics | Properties<br>Conditions | | |

*Table 5: Search terms SLR 2 Q2*

5. Search log
   Sub question 1: What are the characteristics necessary for the raw material to be stored in a Silo and discharged from Silo?

| Date | Database | Query | #hits (relevant) | Retrieved articles |
|---|---|---|---|---|
| 4/4/2022 | Science Direct | (Characteristics OR properties) AND ("Silo storage" OR "Bin storage" OR "Bulk storage") and ("Raw material" OR resource OR component) | 2236(+- 10% relevant) | 1 (2nd article by snowballing author) |

| | | | | |
|---|---|---|---|---|
| 4/4/2022 | Scopus | ( TITLE-ABS-KEY ( characteristics OR properties ) AND TITLE-ABS-KEY ( "Silo storage" OR "Bin storage" OR "Bulk storage" ) AND TITLE-ABS-KEY ( powder ) ) | 24 ( +- 10 relevant) | 2 |

*Table 6: Search log SLR 2 Q1*

Sources:
From search1: (Fürll & Hoffmann, 2013) and (Mellmann, Hoffmann, & Fürll, 2014)
From search 2: (Rooda, 1975) and (Lanzerstorfer, 2020)

Sub question 2: What are the characteristics necessary for the raw material to be transported through vacuum tubes?

| Date | Database | Query | #hits (relevant) | Retrieved articles |
|---|---|---|---|---|
| 29/3/2022 | Scopus | Title(Vacuum AND (conveying OR transport)) AND tilte-abs-key(powder)) | 21(30% relevant) | 0 |
| 29/3/2022 | Scopus | ( TITLE ( "Vacuum transport" OR "vacuum conveying" OR "pneumatic transport" OR "pneumatic conveying" ) AND TITLE-ABS-KEY ( powder AND characteristics ) ) | 100 (+-15% relevant) filter only open access 16 hits | 2 |

*Table 7: Search log SLR 2 Q2*

Sources:
From search 2: (Pan, Mi, & Wypych, 1994) and (Mošorinski, Prvulović, & Palinkaš, 2017)

6. Conceptual matrix

Theme: Characteristics of raw material for bulk storage and vacuum transport

The concepts have quite a lot of overlap therefore, the concepts are marked which are most related to the articles.

| Article↓\concepts→ | Bulk storage | Silo/bin/hopper discharge | Powder flow | Vacuum Transport | Raw material properties |
|---|---|---|---|---|---|
| (Fürll & Hoffmann, 2013) | | | | | |
| (Mellmann, Hoffmann, & Fürll, 2014) | | | | | |
| (Rooda, 1975) | | | | | |
| (Lanzerstorfer, 2020) | | | | | |
| (Pan, Mi, & Wypych, 1994) | | | | | |
| (Mošorinski, Prvulović, & Palinkaš, 2017) | | | | | |

*Table 8: Concept matrix SLR 2*

7. See thesis