UNIVERSITY OF TWENTE.

Besi

The Optimal Model-Based Definition to Reduce Engineering Hours for Besi Packaging

Bachelor Thesis Industrial Engineering & Management

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Preface

The bachelor thesis in front of you is conducted in the field of Industrial Engineering and Management at the University of Twente and Besi Packaging. Besi Packaging strives for a reduction of engineering hours in the Trim & Form Engineering department. Besi Packaging hired me, a Bachelor student of Industrial Engineering & Management for the research. The research concerns the reduction of engineering hours by working with a Model-Based Definition.

I want to thank Jeroen S., Juul, Ton, and all other co-workers at Besi Packaging for their assistance and the wonderful time. From the first day, I have felt very welcome.

On top of that, I want to thank the University of Twente supervisors Leo van der Wegen and Mahak Sharma. The support and feedback provided by them increased the quality of the thesis.

It was an honour to conduct the research.

Laura Eekelder

3rd of August 2023

Management summary

The problem Besi Packaging affronts is a lot of engineering hours. The high amount of engineering hours results in a backlog and high costs (e.g., extra labour costs). Besi Packaging has a potential solution, a Model-Based Definition. The feasibility of the Model-Based Definition is unknown; therefore, the research is set up. The research determines the optimal Model-Based Definition to reduce engineering hours.

The research has several criteria and alternatives. The criteria are the engineering hours [hours], investment costs [euros] and operational costs [euros]. The one-off investment costs contain four software licenses, two-day training, and customized drawings. The operational costs are the yearly maintenance costs when operating with a Model-Based Definition. The engineering hours are the average time an engineer requires to finish the models for a tool. The average time to finish the tool models consists of detailing, modelling, and checking tool models.

Furthermore, the alternatives are the possible Model-Based Definition. In total seven possible Model-Based Definitions exists. The criteria and alternatives correspond with the analytical hierarchy process. Table 1 depicts the overview of the possible Model-Based Definitions with the corresponding criteria values and scores.

Table 1 Overview Possible Model-Based Definitions with Corresponding Scores

Possible Model-Based Definition	Engineering hours [hours]	Investment costs [euros]	Operational costs [euros]	Engineering hours criterion score (w_1=0.777)	Investment costs criterion score (w_2=0.155)	Operational costs criterion score (w_3=0.069)	Overall score
MBD 1	98.38	0	0	0.027	0.199	0.181	0.064
MBD 2	96.76	30600	3600	0.213	0.080	0.098	0.185
MBD 3	97.36	0	0	0.096	0.199	0.181	0.118
MBD 4	97.97	0	0	0.041	0.199	0.181	0.075
MBD 5	96.96	15300	1800	0.166	0.136	0.147	0.160
MBD 6	97.36	15300	1800	0.096	0.136	0.147	0.106
MBD 7	96.35	45900	5400	0.361	0.050	0.065	0.293

According to the analytical hierarchy process the alternative with the highest score is optimal. Therefore, MBD 7 is optimal and results in an engineering hours reduction of 3.65% compared to the total engineering hours average of 100 hours without Model-Based Definition. Whilst the required reduction of engineering hours to earn back the costs within five years is 1.62%. Therefore, the optimal Model-Based Definition 7 is recommended.

Furthermore, the research showed a significant difference in the planned engineering hours and the actual engineering hours which influences the outcome of the research. The planned- and actual engineering hours are used to determine the current total engineering hours average. The limitation of the research is the reduced scope since the Model-Based Definition has cross-departmental impacts. The future scope is a further investigation of Model-Based Definition in the Production- and Quality Control department. Moreover, the T&F Engineering department is recommended to start testing with the software provided by the company B&W Software.

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1. Introduction

Chapter 1 provides the introduction to the research and problem description. Furthermore, Chapter 1 opens with Section 1.1 presenting a description of Besi Packaging. Thereafter, Section 1.2 is described depicting the identification of the action problem. The problem cluster and motivation of the core problem are depicted in Section 1.3. Section 1.4 contains the problem definition. The description of the Model-Based Definition, described in Section 1.5, results from the problem definition. The scope reduction is described in Section 1.5.1, arising from the Model-Based Definition description. The stakeholders are described in Section 1.6. Section 1.7 is separated in Section 1.7.1 and Section 1.7.2, where Section 1.7.1 presents a brief description of the analytical hierarchy process theoretical perspective. Section 1.7.2 explains the choice of the theoretical perspective for the research. Thereafter, the problem-solving approach with research questions is presented in Section 1.8. The deliverables are depicted in Section 1.9. Chapter 1 concludes with the limitations of the research in Section 1.10.

1.1 Description of Besi Packaging

Besi Packaging operates in the back end of the semiconductor industry. The company operates and produces in numerous countries. The Project Engineering department and a section of the Quality Control department are located in the Netherlands and Malaysia. The Production department and the other section of the Quality Control department are located in China (Besi Leshan) and Malaysia (Besi Apac). The consequence of operating and producing in numerous countries is a complex business process model. Furthermore, Besi Packaging fabricates customer-specific tools that are an element of a machine. The tool performs a specific processing step within a production process. The machine consists of composed tools which e.g., produce a microchip. As the customer order appears, the Project Engineering department starts designing the tool model. The tool model consists of a 3D model and a 2D drawing containing all engineering information. As the Project Engineering department finishes the designs, the Production department can start producing the components of the physical tool. The Quality Control departments start after the production steps are completed.

On top of that, the Project Engineering department of Besi Packaging consists of sub-departments. The sub-departments are the Trim & Form (T&F) -, Molding -, and Singulation department. The Molding department develops moulds with which customer components can be encapsulated using liquified plastic. The Molding department has less problems designing tools in comparison to the other sub-departments. The Singulation department designs the tool that cuts the lead frame. The Singulation department consists of a significant amount of automation. Therefore, the efficiency corresponding to the automation of the current way of operating can be achieved in the Trim & Form Engineering department.[1]

The Trim & Form Engineering department develops tools for the trim and form process of semiconductor products. The customer-tailored 3D model made in the T&F Engineering department is based on customer product requirements. The tool model is generated utilizing relationships and parameters with the product drawing of the customer product requirements as input. The tool model is the total tool assembly

[1] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (T&F), Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) (T&F), Mechanical Engineer (16 years employed at Besi Netherlands Packaging) (Singulation), Mechanical Engineer (35 years employed at Besi Netherlands Packaging) (Molding) & Mold Engineer (16 years employed at Besi Netherlands Packaging) (Molding). The interviews were conducted separately, resulting in 5 conducted interviews.

of assembled parts, product-related parts, standard parts, and purchase parts. The various parts are modelled in the 3D model. In Figure 1 an assembled tool of the T&F Engineering department is depicted (Refer Figure 1). [2]

Figure 1 Assembled T&F Tool

1.2 Identification of the action problem

In the Trim & Form Engineering department, twelve engineers are employed. An average of 240 tool models per year are generated by the Trim & Form Engineering department. Furthermore, a backlog of 11 weeks applies from week 18 till week 22 of the year 2023. In Figure 2, the backlog of the T&F Engineering department for the year 2023 is depicted. The text cloud in Figure 2 presents the incoming orders from week 18 till week 22 (green area). The average backlog of the year 2022 is a backlog of 16 weeks, which causes customers to wait for the order. Therefore, the action problem of Besi Packaging is a lot of engineering hours in the T&F Engineering department (Refer Figure 2).[2 3]

[2] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (T&F) and the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) (T&F). The interviews were conducted separately, resulting in 2 conducted interviews.

[3] The information was obtained through one physical semi-structured interview with the Manager Project Engineering (22 years employed at Besi Netherlands Packaging).

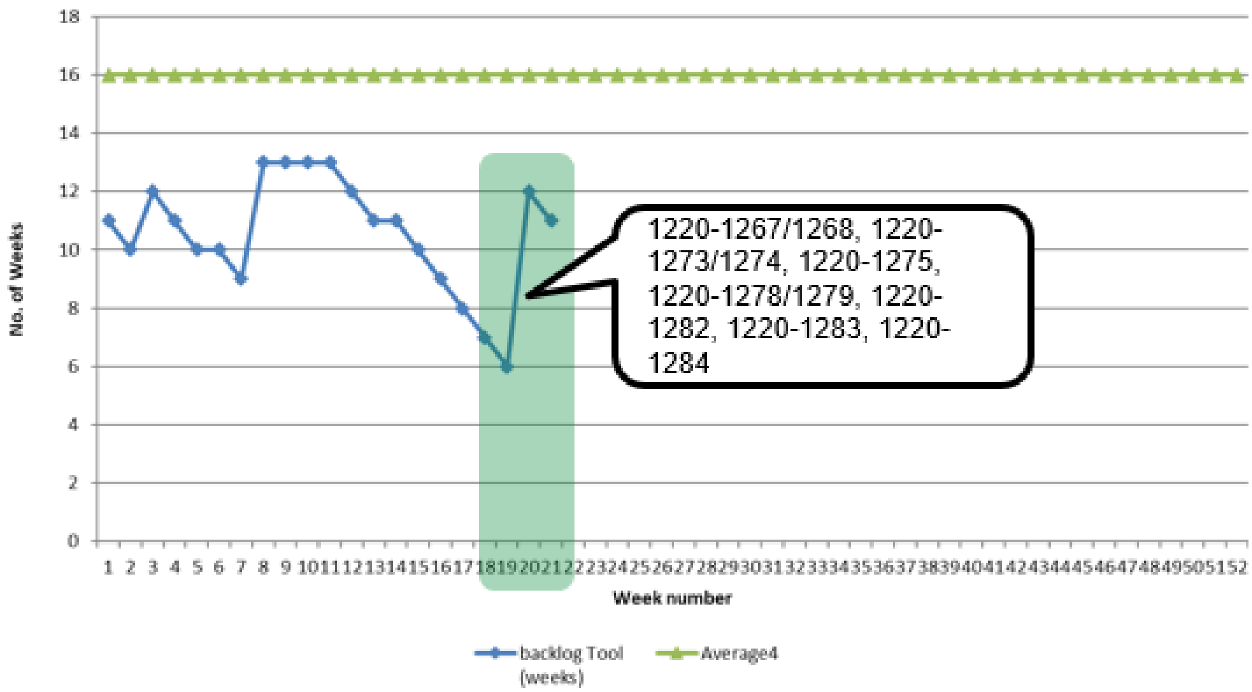

Figure 2 Trim & Form Engineering Department Backlog

1.3 Problem cluster and motivation of the core problem

The action problem Besi Packaging affronts is a lot of engineering hours. The high amount of engineering hours results in the backlog addressed in Section 1.2. Moreover, additional costs are a consequence, such as extra labour costs. The inefficient implementation of engineering data in a tool model causes the excessive quantity of engineering hours. In other words, the core problem is the inefficient implementation of the engineering data in a tool model. In Figure 3 the problem cluster of the highlighted action problem is depicted.[4]

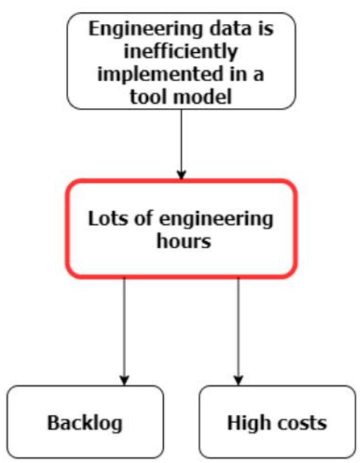

Figure 3 Problem Cluster

[4] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (T&F) and the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) (T&F). The interviews were conducted separately, resulting in 2 conducted interviews.

1.4 Problem definition

Besi Packaging has a potential solution for the core problem of inefficient implementation of engineering data in the tool model. The potential solution is a Model-Based Definition. A Model-Based Definition is an approach for a 3D model containing all the product and manufacturing information. At present, Besi Packaging is oblivious to the feasibility of a Model-Based Definition and the corresponding reduction of engineering hours. In other words, the problem definition is the nescient of the feasibility of the Model-Based Definition. Therefore, the research will determine the optimal solution regarding Model-Based Definition with the corresponding reduction of engineering hours. Thereafter, Besi Packaging can determine whether implementing a Model-Based Definition is feasible and profitable in terms of efficiency gains. Therefore, the problem (challenge) is solving the main research question "*What is the optimal Model-Based Definition to reduce engineering hours for the T&F Engineering department of Besi Packaging?*". The challenge results in the problem of choosing the best Model-Based Definition. [5]

1.5 Model-Based Definition description

The Model-Based Definition is an approach to implement all the product and manufacturing information in the 3D model. Among other things, the product and manufacturing information is the tolerances, assembly, and geometrical information. The product and manufacturing information will not alter content-wise due to a Model-Based Definition, but the presentation of the product and manufacturing information will modify. The Model-Based Definition has the main strength to have benefits throughout the entire company, e.g., a benefit for production of the Production department is a coupling between the Model-Based Definition and the production machines. The Model-Based Definition has a Computer Aided Design (CAD), which allows the coupling in production with the Computer Aided Manufacturing (CAM) software. The coupling in the production of the Production department (i.e., automation) results in more benefits. The automatization in the production of the Production department results in less mistakes and less knowledge required in the department since the knowledge is placed in the 3D model containing the Model-Based Definition and the production machines. Moreover, less mistakes happen when quitting operating manually. Therefore, a reduction in material costs can be realized. The Model-Based Definition reduces the engineering hours and improves the quality of the product. The quality of the product improves due to the automatization in the production of the Production department. [6] *(Xu et al., 2022) (Ramnath et al., 2020) (Jian et al., 2021)*

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[5] The information was obtained through one physical semi-structured interview with the Manager Project Engineering (22 years employed at Besi Netherlands Packaging).

[6] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (T&F) and the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) (T&F). The interviews were conducted separately, resulting in 2 conducted interviews.

In Figure 4 an example of the 3D model with Model-Based Definition is depicted for a tool of the T&F Engineering department. The picture is generated by the Senior Tool Engineer.[7]

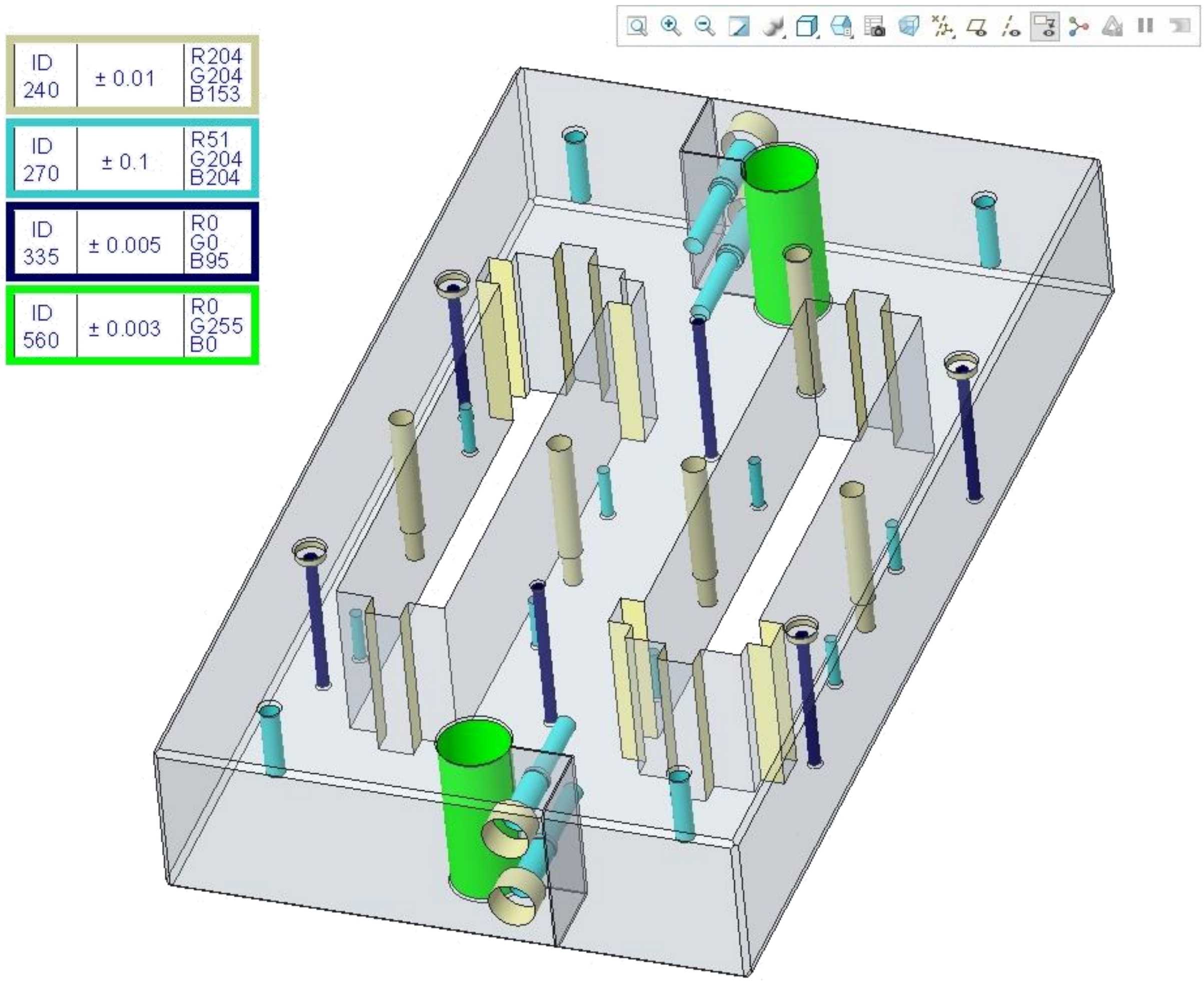


Figure 4 Model-Based Definition Example

1.5.1 Scope reduction

Presenting the product and manufacturing information in a different way has enormous impacts on the downstream departments in the production chain of the company. The production of the Production department and Quality Control department must operate differently. On top of that, if the supplier of outsourced part production cannot operate with the Model-Based Definition, the supplier of outsourced part production must align with the new manner of operating the data. In other words, starting to operate with a Model-Based Definition has major impacts on the company. Implementing the Model-Based

[7] The information is obtained by the Senior Tool Engineer (15 years employed at Besi Netherlands Packaging) testing the B&W Software software. The interview with the CEO of B&W Software, resulted in test licenses for the Model-Based Definition software program.

Definition in the company will take several years. Therefore, the research has a reduction in scope. The scope of the research is reduced to the T&F Engineering department of Besi Packaging. [8]

1.6 Stakeholder analysis

The stakeholder analysis contains the distinction between involvement and importance. The involvement implies the interest of the stakeholder regarding the research. The importance implies the authority of the stakeholder regarding the research. E.g., high importance presents the stakeholder deciding on the amount of money to invest in the research. *(Martins, 2023)*

Firstly, the T&F engineers are a stakeholder. The outcome of the research might result in a different way of working for the T&F engineers. Moreover, the engineers are involved in the research. The engineers function as a source of information for the research. Therefore, many interviews will be conducted with the T&F engineers. In other words, the engineers contain essential information for the research. Therefore, non-stop contact is required.

Secondly, the Besi management board is a stakeholder. The Besi management board has much power regarding the research. On top of that, the Besi management board is responsible for the targets made, and the profitability of the production program. Therefore, the importance of the Besi management board is high. Moreover, the Besi management board will decide on the follow-up of the Model-Based Definition within Besi Packaging. The Besi management board has a low involvement concerning the research. Therefore, the Besi Packaging management board is kept informed by minimal contact.

Thirdly, the company B&W Software functions as a stakeholder. Information will be retrieved from the stakeholder as input for the research. Moreover, B&W Software potentially benefits from the research in terms of money depending on the research results. The contact is minimal, but the company contains essential information.

Fourthly, the Manager Project Engineering has a high involvement and high importance in the research. Regular meetings will be held with the Manager Project Engineering. On top of that, the Manager Project Engineering functions as a source for the research. Furthermore, the Manager Project Engineering set up the research with the management board, therefore the Manager Project Engineering must deliver the research to the management board. Which makes the involvement of the Manager Project Engineering high. On top of that, the research must fulfil all the requirements of the Manager Project Engineering, which makes the importance of the Manager Project Engineering high. Therefore, the Manager Project Engineering is kept informed which requires regular contact.

[8] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (T&F) and the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) (T&F). The interviews were conducted separately, resulting in 2 conducted interviews.

In Figure 5 the stakeholder analysis is depicted.

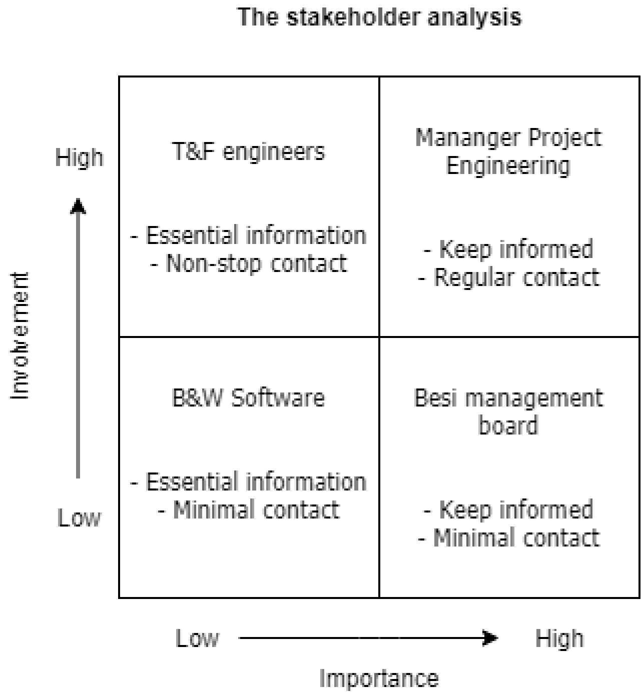


Figure 5 The Stakeholder Analysis

1.7 Theoretical perspective

In Section 1.7.1 a brief description of the analytical hierarchy process theoretical perspective is presented, and Section 1.7.2 explains the choice of the theoretical perspective for the research.

1.7.1 Brief description of the AHP theoretical perspective

The multi-criteria decision analysis (MCDA) is a structured method to determine the optimal solution considering multiple criteria and alternatives. The MCDA has a goal that is reached with alternatives and criteria. The MCDA has the advantage to be applicable in many disciplines. The criteria function as measurements for the alternatives. Trade-offs are made in the criteria- and alternatives weights. In other words, the MCDA is a guide in the decision-making process that works towards a goal *(Indeed Editorial Team, 2023).*

A variant of the MCDA is the analytical hierarchy process (AHP). The advantages of the analytical hierarchy process are the numerous criteria that are admitted, simple operation, developed method, possible application in numerous cases, and reliability inspection (*Bhasin, 2023).* However, the disadvantage of the analytical hierarchy process is the limited pairwise comparisons. In other words, the AHP limits the number of alternatives. On top of that, a requirement of the analytical hierarchy process is that the AHP does not permit overlap between the criteria *(The Analytic Hierarchy Process – IspatGuru, n.d.).* The theoretical perspective in the research is the analytical hierarchy process (AHP).

1.7.2 Explained choice of the AHP theoretical perspective

The goal of the research is to find the optimal Model-Based Definition to achieve a reduction of engineering hours. The criteria in the research are defined to determine which Model-Based Definition is optimal (Chapter 2). Thereafter, the alternatives are determined (Chapter 3). The alternatives are the different Model-Based Definitions. At last, after gaining all the input for the analytical hierarchy process. The structured method of the AHP is applied (Chapter 4), i.e., the problem in the research is solved with the analytical hierarchy process. The conclusion of the analytical hierarchy process with the corresponding recommendations is depicted in Chapter 5.

1.8 Problem-solving approach with research questions

The problem-solving approach comprises the analytical hierarchy process (the theoretical perspective). Chapter 1 identifies the problem, the goal, and formulates the approach to the research. Chapter 2 describes the analysis of the current situation and the corresponding criteria. Subsequently, the possible Model-Based Definitions are described in Chapter 3. In other words, the alternative generation with thereafter the corresponding criteria scores. The optimal Model-Based Definition is determined in Chapter 4 with the structured steps of the analytical hierarchy process (described in Section 4.1) *(Indeed Editorial Team, 2023).*

Chapter 2 Current situation description

To retrieve an understanding of the T&F Engineering department, the sub-question "*What is the current business flow of a tool in the T&F Engineering department of Besi Packaging?* " will be answered. Moreover, the sub-question provides insight into the location of the effect of operating with a Model-Based Definition in the Trim & Form Engineering department. To answer the sub-question, interviews will be conducted. In the appendix the elaboration of the conduction of interviews is depicted. The information retrieved regarding the sub-question will be worked out in a business process model. The business process model presents an overview of the answer to the sub-question.

Secondly, the sub-question "*What information is currently placed in a 2D drawing of the T&F Engineering department of Besi Packaging?*" will be answered in Chapter 2. The answer will be established by conducting interviews with the Mechanical Engineer, Senior Tool Developer, and two Senior Tool Engineers of the T&F Engineering department. Therewithal, drawing packages will be chosen by the interviewed employees. The drawing packages will be analysed manually with different colours and registered in an Excel file. The analysis and the interviews will answer the sub-question.

Thirdly, the sub-question "*What are the current costs, lead time, and engineering hours in the T&F Engineering department of Besi Packaging?* " will be answered in Chapter 2. The Mechanical Engineer, Senior Tool Developer, two Senior Tool Engineers of the T&F Engineering department, and the Manager of Project Engineering will be interviewed to collect information for answering the sub-question. When the research was appointed by the Besi management board, the management board indicated the costs, lead time and engineering hours as important criteria to determine whether a Model-Based Definition is feasible. Therefore, the sub-question was created.

Chapter 3 Alternatives, criteria, and data generation

In Chapter 3 the sub-question "*What are possible Model-Based Definitions for the T&F Engineering department of Besi Packaging?*" will be answered. The necessary information for answering the sub-question is retrieved by interviewing the company B&W Software, the Mechanical Engineer, Senior Tool Developer, and two Senior Tool Engineers of the T&F Engineering department. A semi-structured interview will be conducted with the company to retrieve the information. The interview requires preparation, whilst the company provides its own input, which is retrieved in a way that resembles a conversation. Furthermore, unstructured interviews will be conducted with the Mechanical Engineer, Senior Tool Developer, and two Senior Tool Engineers of the T&F Engineering department to retrieve the information regarding the possible Model-Based Definitions for the sub-question. The interviews are unstructured since the interviews take the form of a conversation. The possible Model-Based Definitions are the alternatives in the analytical hierarchy process.

Moreover, in Chapter 3 the sub-question "*What are the criteria of the possible Model-Based Definition for the T&F Engineering department of Besi Packaging?* " will be answered. To answer the sub-question, the Manager Project Engineering of the T&F Engineering department will be interviewed in a semi-structured interview. Thereafter, the Manager Project Engineering will consult the Senior Vice President Packaging whether the criteria comply with the stakeholder Besi management board.

Furthermore, the sub-question "*What are the corresponding scores on the criteria for possible Model-Based Definitions for the T&F Engineering department of Besi Packaging?"* will be answered. E.g., the new reduced engineering hours for the possible Model-Based Definitions. For the sub-question, the sub-questions "*What are possible Model-Based Definitions for the T&F Engineering department of Besi Packaging?*" and "*What are the criteria of the possible Model-Based Definition for the T&F Engineering department of Besi Packaging?* " will be used as information input. On top of that, the Mechanical Engineer, Senior Tool Developer, two Senior Tool Engineers of the T&F Engineering department, and the Manager of Project Engineering will be interviewed to collect the numerical data for the sub-question.

Chapter 4 Solution choice

In Chapter 4 the analytical hierarchy process calculation steps will be explained and applied with the collected information in Chapter 3. The optimal Model-Based Definition to reduce the engineering hours will be determined. The main research question will be answered: "*What is the optimal Model-Based Definition to reduce engineering hours for the T&F Engineering department of Besi Packaging?*".

Chapter 5 Conclusions and recommendations

Chapter 5 contains the conclusions, recommendations, discussion, limitations, and future scope. The information for the future scope will be retrieved by interviewing the Senior Tool Engineer, Mechanical Engineer, and Senior Production Engineer in semi-structured interviews.

1.9 Deliverables

The business process model of the T&F Engineering department is part of the deliverables. The deliverable is for understanding the main processes in the Trim & Form Engineering department and to understand where the core problem is located. The understanding of the location of the core problem presents where change will apply for the Trim & Form Engineering department. Therefore, the research can anticipate on the change. In Section 2.1 the deliverable is depicted.

Furthermore, part of the current situation description is the drawing packages analysis. The drawing packages analysis is performed to collect the product and manufacturing information that is currently placed in a 2D drawing. The drawing analysis clarifies the current situation and what the possible Model-Based Definitions are. In Section 2.2 the deliverable is depicted.

On top of that, the possible Model-Based Definitions with the corresponding criteria are a deliverable. The deliverable functions as the input for the analytical hierarchy process to determine the optimal Model-Based Definition to reduce the engineering hours. The deliverable can be found in Section 3.1.

Moreover, the optimal Model-Based Definition to reduce engineering hours will be delivered with the corresponding criteria. The optimal Model-Based Definition with the corresponding criteria can be found in Section 4.3.

1.10 Limitation

The limitation of the research is the reduced scope. Model-Based Definition has an enormous impact on several departments of the company. The research has limited time, which results in a focus on one of the Project Engineering departments. Therefore, when implementing a Model-Based Definition more benefits will occur than stated in the report. On top of that, more changes in the company need to be considered. For example, a change in the company is the operation of production of the Production department. The consequence is further investigation is required for Besi Packaging when the recommendation of the research is positive for implementing a Model-Based Definition in the T&F Engineering department. The additional benefits, change, etc. are not performed in the research which is a limitation. Whilst the results of the research are used, the limitations must be considered. In Section 5.3 the elaboration on the limitation of the research is depicted.

2. Current situation description

Chapter 2 depicts the current situation of the Trim & Form Engineering department. The chapter opens with Section 2.1 describing the current business flow of a tool in the Trim & Form Engineering department. Thereafter, the current information in the 2D drawing is displayed in Section 2.2. Section 2.3 contains the current costs, lead time and engineering hours. Section 2.4 contains the conclusion of Chapter 2.

2.1 Current business flow of the T&F tool

To retrieve an understanding of the T&F Engineering department and the location of the influence of the Model-Based Definition the sub question "*What is the current business flow of a tool in the T&F Engineering department of Besi Packaging*?" is answered in this section.

The process of engineering starts with the appearance of the customer demand. In other words, the customer has a request for a product. The Customer Project Manager processes the customer order and the corresponding documentation. The order plan and the processing are done by the Customer Project Manager. The APD (Approval Project Document) and datasheet are components of the processing. The order plan determines the time consumed for a project. Engineers receive input from the Customer Project Manager with the corresponding customer files necessary for the tool design. In Figure 6 the beginning of the business flow of the T&F Engineering department tool is depicted.

In the event of odd elements detected by engineers in the input of the Customer Project Manager, the engineers inform the Customer Project Manager. The Customer Project Manager is in contact with the customer and informs the customer whether the odd aspect was consciously done or a mistake. In case of solving the odd aspects or if odd aspects have not occurred, the engineer starts designing the 2D tool layouts in BricsCAD. The customer files are used as input for designing the 2D tool layout. For forming, an additional forming layout is required in comparison to the other processes (e.g., trimming). The forming process requires a consideration of the measure and cut length. Odd aspects could arise while designing the 2D tool/forming layout in BricsCAD. In case of noticing odd aspects, the Customer Project Manager will be informed.

Subsequently, the 3D tool model is designed based on the tool and forming layout. The lead frame of the tool house is designed with the forming layout. The 3D models in Creo have no tolerances. The tolerances remain in the 2D tool/forming layout (Refer Figure 6).

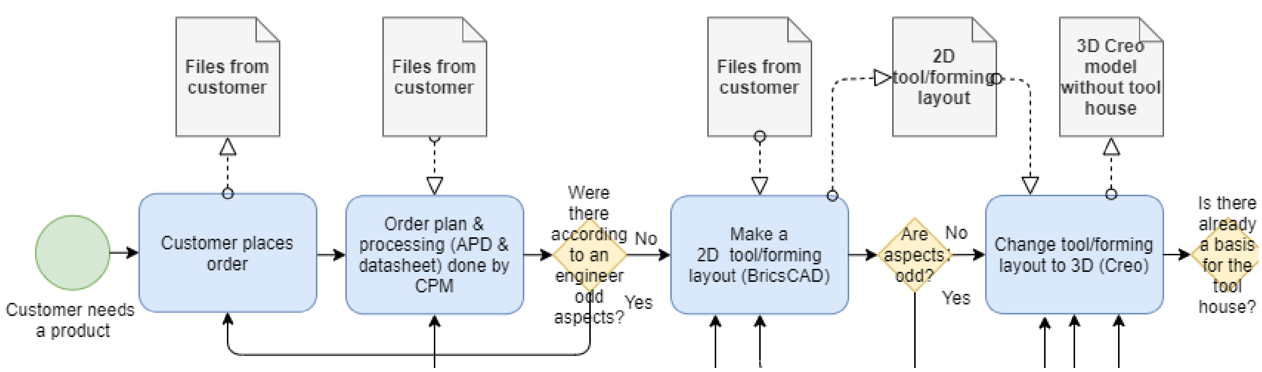


Figure 6 Business Process Model Part 1

Furthermore, the process reaches two separate paths. In Figure 7, the continuation of the business flow of the tool in the T&F Engineering department is depicted. The first path is selected in the case of an existing similar tool house. The tool house modelling is simple for the first path since a similar tool house is used to create a 3D model with a tool house. The second path is selected in case of a non-existing similar tool house. The second path requires the engineer to design a tool house from scratch. The second path demands more time in comparison to the first path. The output of both paths is a 3D model with a tool house. Therefore, the different paths merge when the tool house is generated.

Thereafter, a determination is required if the checklist is verified before. When a tool did not comply with the checklist, a return in the process is mandatory. If the specific element of the checklist is modified, the continuation of the process is allowed. The continuation of the process results in uploading the files in Pro/Intralink. In the event of not conducting the checklist prior, the continuation of the process after generating the tool house is designing a design review document. The design review document is a PowerPoint presentation. The 3D Creo model with tool house is the input for the design review document. The design review document operates as guidance for the internal discussion of the design of the engineer.

Concluded from the internal discussion, the 3D Creo model can be labelled as insufficient. The engineer receives the task to restore the 3D Creo model in prior processes. The prior processes to return are the tool house modelling, changing the tool/forming layout to the 3D model, or designing the 2D tool/forming layout in BricsCAD (Refer Figure 7).

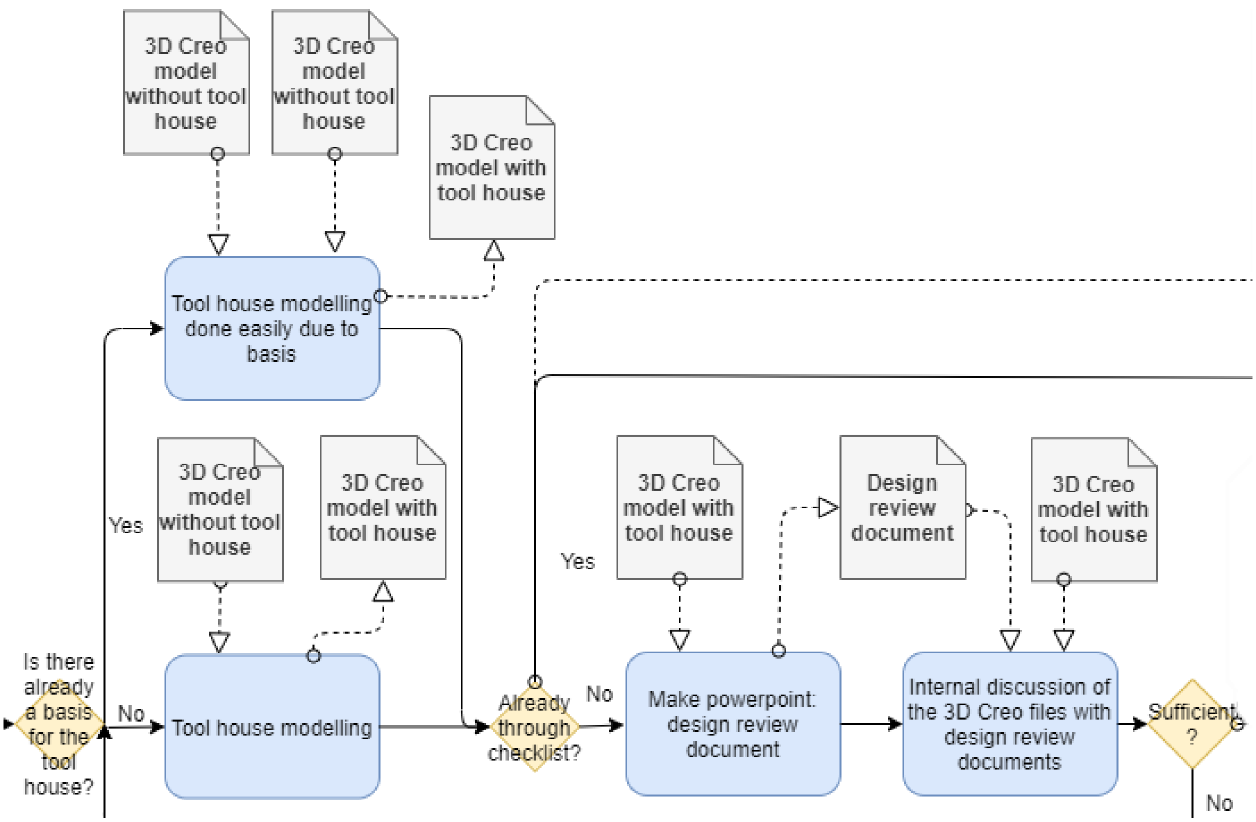


Figure 7 Business Process Model Part 2

Moreover, the internal discussion can lead to the approval of the design. The continuation of the process is the start of detailing the 3D Creo model and generating 2D drawings in Creo. The 3D Creo model with tool house is the input for the process. The output of the process is a detailed 2D Creo drawing. In Figure 8, the continuation of the business flow of the tool in the T&F Engineering department is depicted.

The core problem is depicted in the step "work 3D model out in detail on a 2D drawing". In Figure 8 the location of the core problem in the business process model of the Trim & Form Engineering department is depicted. Therefore, working with a Model-Based Definition will have the most impact on working the 3D model out in detail on a 2D drawing.

Thereafter, the 2D Creo drawing progresses through the T&F checklist. The insufficient result of the checklist results in a return to prior processes (Refer Figure 8).

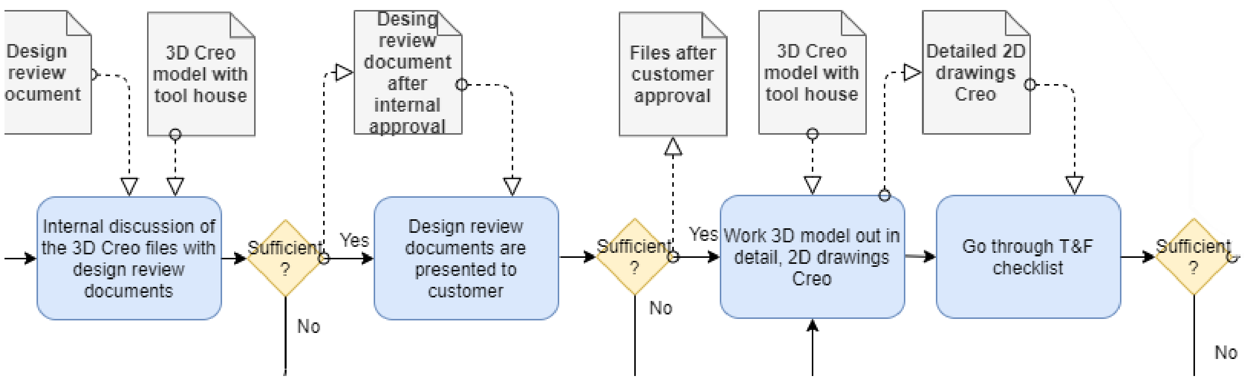


Figure 8 Business Process Model Part 3

The sufficient result of the checklist results in the upload to Pro/Intralink. In Figure 9 the end of the business flow of the tool in the T&F Engineering department is depicted. The upload to Pro/Intralink results at the end of the process if no action is taken. In Pro/Intralink the action promote as designed is obligatory to be carried out. The action results in the upload of the 3D model and 2D drawings, the tool layout, the design review document, and the checklist to Agile. The files arrive with the state 2100 in Agile. The state change in Agile from 2100 to 2400 results in the sending of the transfer mail. The supply chain process launches merely by obtaining the transfer mail (Refer Figure 9).[9]

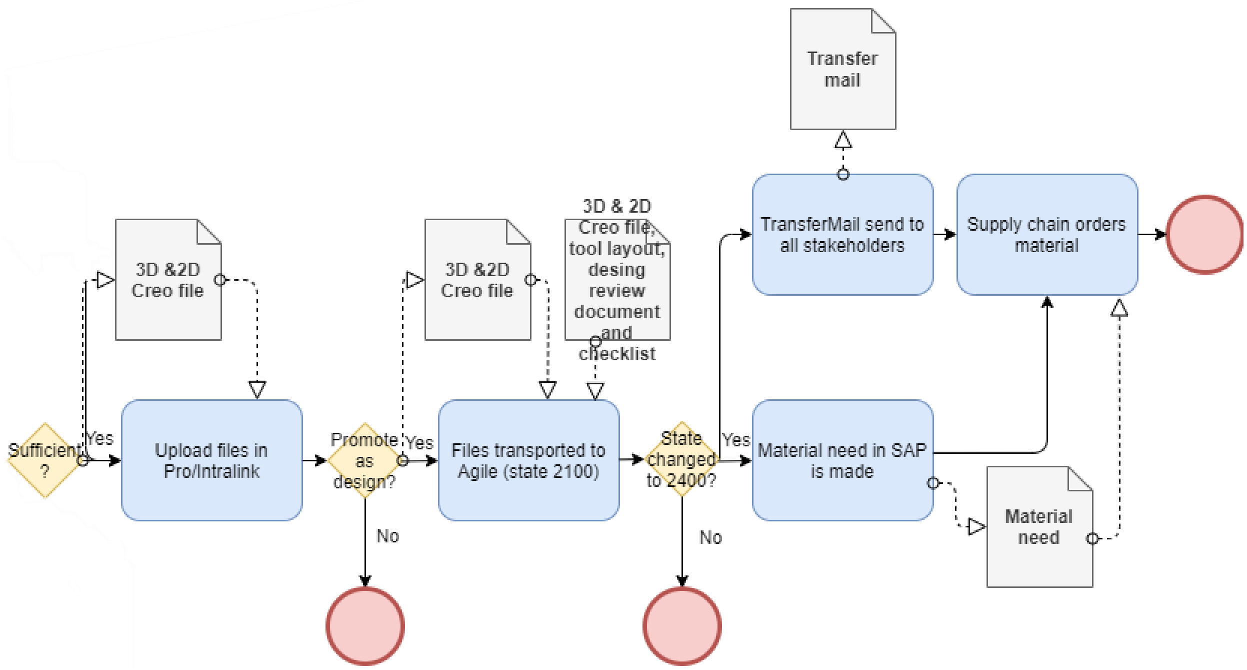


Figure 9 Business Process Model Part 4

The appendix contains the attached business process models.

2.2 Current information in the 2D drawing

The location of the impact of the Model-Based Definition is answered in the former section. That is, the main impact of a Model-Based Definition on the T&F Engineering business flow is on the task of "working the 3D model out in detail on a 2D drawing". In this section the sub-question "*What information is currently placed in a 2D drawing of the T&F Engineering department of Besi Packaging?*" will be answered. A Model-Based Definition modifies the way of presenting the product and manufacturing information, but the product and manufacturing information remains the same. Therefore, the sub-question clarifies the elements of the product and manufacturing information the Model-Based definition must contain.

[9] The information was obtained through physical unstructured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging), Senior Tool Developer (40+ years employed at Besi Netherlands Packaging), and two Senior Tool Engineers (35 years employed at Besi Netherlands Packaging & 15 years employed at Besi Netherlands Packaging) of the T&F Engineering department. The interviews were conducted separately, resulting in 4 conducted interviews.

The sub-question "*What information is currently placed in a 2D drawing of the T&F Engineering department of Besi Packaging?*" is solved with the analysis of drawing packages. In total four drawing packages are analysed. The four drawing packages are the Dambar Cutting tool, the Forming tool, the Final Cutting tool, and the Separating tool. Drawing packages consist of separate part drawings. Figure 10 presents a drawing part of the Separating tool (Figure 10 is not readable due to the small size, the unreadability is done deliberately since Figure 10 serves as a presentation for the complexity of the 2D drawing) (Refer Figure 10).[10]

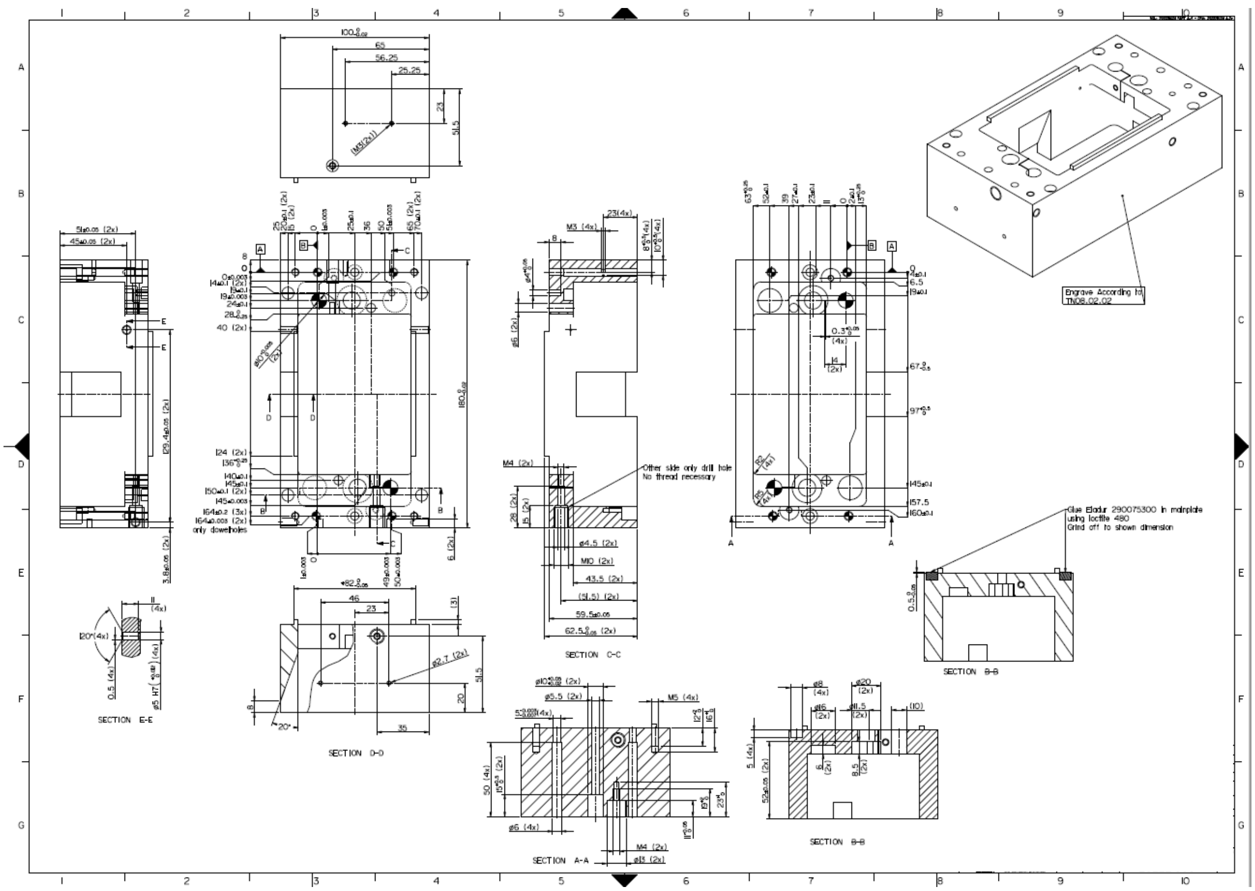


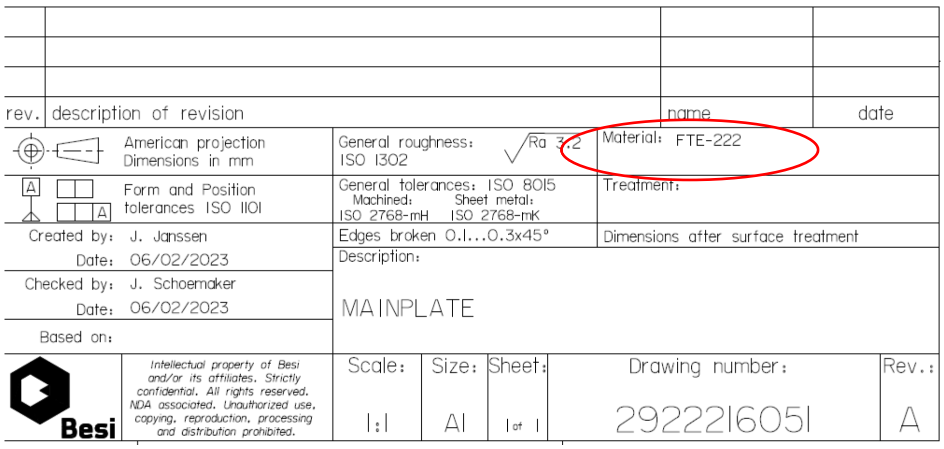
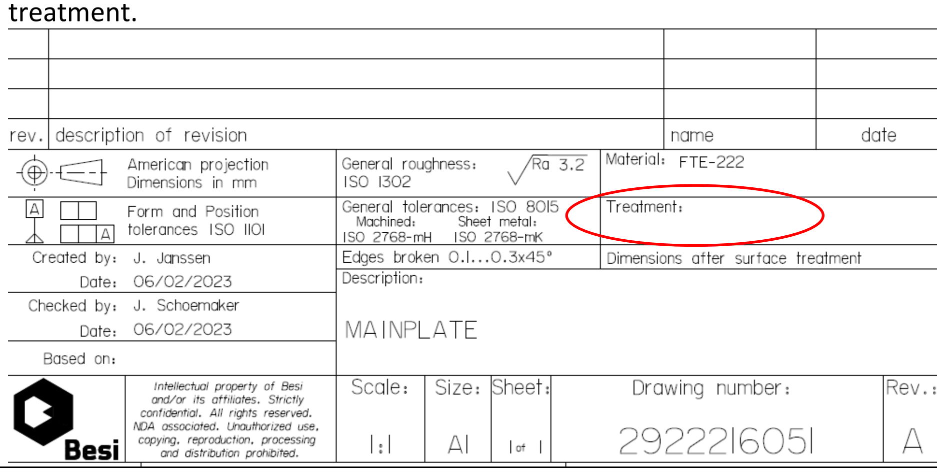
Figure 10 2D Drawing Example

Furthermore, Table 2 is based on the separate part drawings. Table 2 presents the main findings of the detailed analysis. In other words, the current information placed in the 2D drawing of the T&F Engineering department of Besi Packaging is presented in Table 2. Table 2 is necessary to determine the possible Model-Based Definitions. The information that is currently placed in the 2D drawings and 3D models, needs to be placed in the 3D model with Model-Based Definition. Model-Based Definition does not change

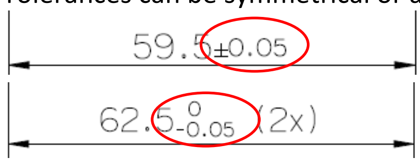
[10] The information was obtained through physical semi-structured interviews with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging), the Mechanical engineer (2 years employed at Besi Netherlands Packaging) and the Senior Tool Developer (29 years employed at Besi Netherlands Packaging). The findings are recorded in the Excel file. The main findings are stated in the report. The interviews were conducted separately, resulting in 3 conducted interviews. Moreover, the interviews resulted in the analysis of four drawing packages.

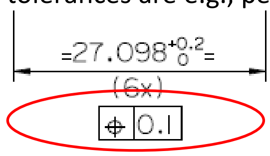
the information that is necessary for production, Model-Based Definition only changes the way of presenting the information. The elaboration of Table 2 depicts an overview, explanations, and examples of the information on 2D drawings. Moreover, the red circles in Table 2 are examples from the actual analysed drawing packages (Refer Table 2).[11]

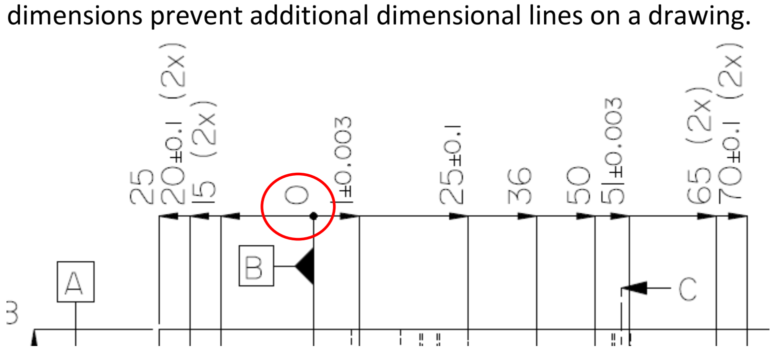
Table 2 The Current Information in the 2D Drawing

<table>
<tr><th>Information on 2D drawings</th><th>Explanation</th></tr>
<tr><td>Tool part material</td><td>The tool part material is specified in a secret code due to confidentiality. For example, FTE-222. The code represents the material a tool part must consist of, e.g., a hard metal Carbide.

</td></tr>
<tr><td>Specific production treatment</td><td>The specific production treatment represents an additional required treatment. For example, HRC 57-59 stands for a hardening process. In the example, a hardness of 57-59 Rockwell C is required. The 2D drawing of Figure 10 contains no additional treatment.

</td></tr>
</table>

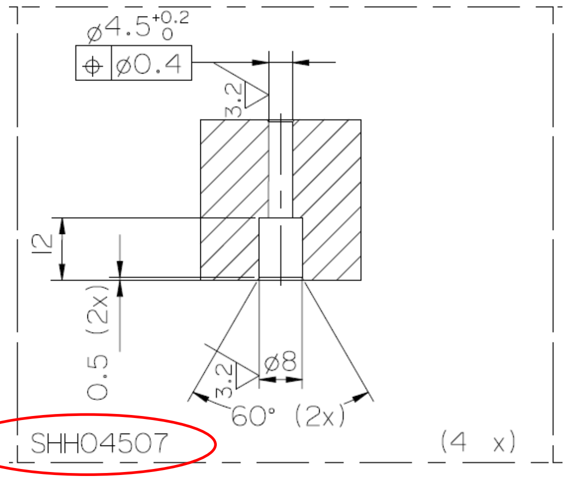
[11] The information was obtained through physical semi-structured interviews with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging), the Mechanical engineer (2 years employed at Besi Netherlands Packaging) and the Senior Tool Developer (29 years employed at Besi Netherlands Packaging). The findings are recorded in the Excel file. The main findings are stated in the report. The interviews were conducted separately, resulting in 3 conducted interviews. Moreover, the interviews resulted in the analysis of four drawing packages.

<table>
<tr><th>Information on 2D drawings</th><th>Explanation</th></tr>
<tr><td>Dimensional tolerances</td><td>The tolerances consider the angle tolerances and the dimensional tolerances. Tolerances can be symmetrical or asymmetrical.


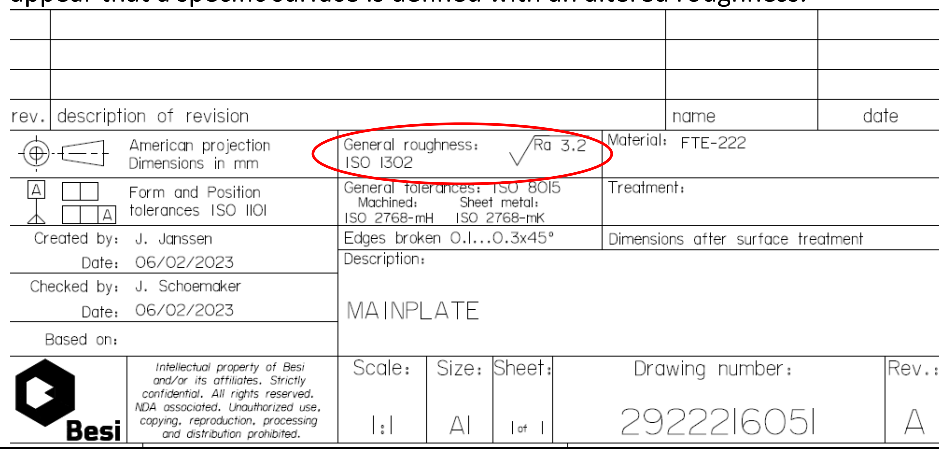
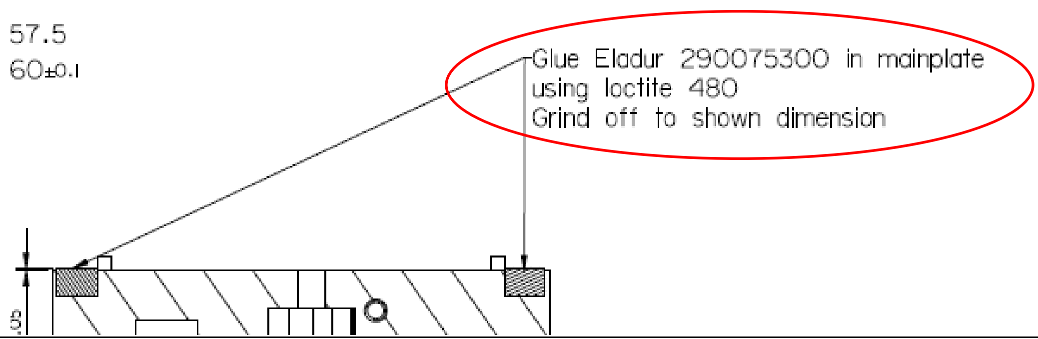
Symmetrical tolerances
Asymmetrical tolerances</td></tr>
<tr><td>Geometric tolerances</td><td>The geometrical tolerances consider the form and position tolerances. The geometrical tolerances are e.g., perpendicularity, flatness, and position tolerances.


An example of the geometric tolerance in a 2D drawing is the position tolerance with a tolerance of 0.1 mm.</td></tr>
<tr><td>Ordinate dimensions</td><td>Ordinate dimensions are dimensions measured from an indicated zero point. Ordinate dimensions prevent additional dimensional lines on a drawing.

</td></tr>
</table>

Information on 2D drawings	Explanation
Hole tables	Hole tables define the sizes and locations of the hole.



Hole	X	Y	Code	Pitch X-line
1	0	90	COL051	
2	0	-90	COL051	
3	-28.325	46.23	CTP05101	1x66.65
4	-35.975	-46.23	CTP05101	1x15.3
5	30.675	-46.23	CTP05101	1x15.3
6	38.325	32.5	DST051	
7	-28.325	24.75	DST051	
8	-28.325	-24.75	DST051	
9	38.325	-32.5	DST051	
10	-31	90	SHH04507	1x62
11	-31	-90	SHH04507	1x62
12	-35.975	46.23	S__001	
13	-20.675	46.23	S__001	1x66.65
14	-28.325	-46.23	S__001	1x66.65
15	-50	90	S__003	1x100
16	-50	-90	S__003	1x100
17	-52	65	THH04003	1x104
18	52	-63	THH04003	
19	-52	-65	THH04003	

<table>
<tr><th>Information on 2D drawings</th><th>Explanation</th></tr>
<tr><td>Roughness</td><td>The roughness presents the surface finish. The drawing has an overall roughness, cases appear that a specific surface is defined with an altered roughness.

</td></tr>
<tr><td>Remarks</td><td>Sometimes additional information is required for production. For example, a mounting instruction is depicted below.

</td></tr>
</table>

In the appendix, an elaboration is given regarding the findings.

2.3 Current costs, lead time and engineering hours

In this section the sub-question "*What are the current costs, lead time, and engineering hours in the T&F Engineering department of Besi Packaging?*" is answered.

The current costs, lead time, and engineering hours are important criteria for one of the stakeholders, the management board of Besi Packaging, concerning the Model-Based Definition. The presence of criteria corresponds to the theoretical perspective of the analytical hierarchy process. The Besi management board desires a comparison of the scores of the optimal alternative and the current way of working on the criteria. In Figure 5 the importance and involvement of the Besi management board is depicted. Figure 5 indicates a high importance of the Besi management board, therefore the demands of the Besi management board need to be satisfied.

The current costs of the T&F Engineering department relevant to Model-Based Definition are the software costs. The costs for computers, the heating of the building, etc. are irrelevant to the research and Model-

Based Definition. Therefore, the software costs are the costs considered. The present (software) costs will not vary when applying the Model-Based Definition. The present software programs in use for the T&F Engineering department of Besi Packaging are Creo Parametric 4.0, Agile, dwg trueviewer, Autocad 2020, Autocad R14 with amelio, Bricscad with romanovski, Adobe, MS Word, MS Excel, and MS ppt. The T&F Engineering department is dependent on software programs. Operating Model-Based Definition will not change the current software programs that are necessary, therefore the current costs remain whilst operating Model-Based Definition.[12]

Furthermore, the lead time is the time a tool requires to go through the entire business flow of the T&F Engineering department (Chapter 2). The engineering hours (effort) is the time an engineer requires to finish the tool. The main time of designing a tool is required by the task of "the work out of the 3D model in detail to 2D drawings". In Figure 8 "the work out of the 3D model in detail to a 2D drawing" is presented in the business flow of the T&F tool of the Engineering department (Refer Figure 8). In Table 3, Table 4, Table 5, and Table 6 the lead time and engineering hours are depicted per drawing package (to design a tool, a drawing package is required). In other words, Table 3, Table 4, Table 5, and Table 6 present the four different tools with the corresponding engineering hours and lead time. The lead time of a tool contains the engineering hours.

On top of that, in Table 3, Table 4, Table 5 and Table 6 the actual engineering hours are depicted as higher than the planned engineering hours, apart from the Final Cutting tool depicted in Table 5. Besi Packaging has a hard time estimating the necessary engineering hours for a tool. For Besi Packaging to generate an accurate planning, the actual- and planned engineering hours should be approximately equal. The information in Table 3, Table 4, Table 5, and Table 6 serve as an information source for the estimation of the reduction in engineering hours for the possible Model-Based Definitions (Refer Table 3, Table 4, Table 5, and Table 6).

Table 3 Engineering Hours & Lead Time for a Dambar Cutting Tool

Dambar Cutting tool				
Engineering hours [hours]		Engineering lead time [hours]		
Planned	*Actual*	*Start date*	*End date*	*The total number of hours*
100	226.5	23/01/2023	31/01/2023	8*24=192

Table 4 Engineering Hours & Lead Time for a Forming Tool

Forming tool				
Engineering hours [hours]		Engineering lead time [hours]		
Planned	*Actual*	*Start date*	*End date*	*The total number of hours*
90	153	7/2/2023	24/02/2023	17*24=408

[12] The information was obtained through one physical unstructured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) of the T&F Engineering department.

Table 5 Engineering Hours & Lead Time for a Final Cutting Tool

Final Cutting tool				
Engineering hours [hours]		Engineering lead time [hours]		
Planned	*Actual*	*Start date*	*End date*	*The total number of hours*
70	52	9/2/2023	7/3/2023	26*24=624

Table 6 Engineering Hours & Lead Time for a Separating Tool

Separating tool				
Engineering hours [hours]		Engineering lead time [hours]		
Planned	*Actual*	*Start date*	*End date*	*The total number of hours*
36	71	1/2/2023	6/2/2023	5*24=120

2.4 Conclusion

The business flow of the T&F tool starts with the customer placing the order. Thereafter, the order plan and processing are done by the Customer Project Manager. In the case of a non-occurrence of odd aspects in the customer files, the business flow continues. Otherwise, a return of process is required. The 2D tool/forming layout is made. Subsequently, the tool/forming layout is changed to 3D (Creo). Thereafter, the tool house is designed. If a comparable tool house exists, the design of the tool house is executed more conveniently. Furthermore, the design review document is generated, with the internal discussion subsequently. If the internal discussion was sufficient, the business flow is continued. Otherwise, a return in the process is necessary. The continuation starts with the detailing of the 3D model in 2D. Thereafter, the checklist is verified. If the checklist is verified, the process continues. Otherwise, a return in the business flow is required. The files designed by the engineer are uploaded, whereas the Supply Chain department starts operating. The core problem lies mainly in working the generated 3D model out in detail in 2D drawings (Refer Figure 8). So, Model-Based Definition mainly changes the task "working the 3D model out in detail to a 2D drawing" of the business flow of the Trim & Form Engineering department. The theory of Model-Based Definition explains the change of the task since MBD is a different approach to presenting the product and manufacturing information.

Furthermore, the current information placed in the 2D drawing is the tool part material, the specific production treatment, dimensional tolerances, geometric tolerances, ordinate dimensions, hole tables, roughness, and remarks. The information on the 2D drawing will not change, only the way of presenting the product and manufacturing information.[13]

On top of that, the current costs will not change for the Trim & Form Engineering department. Therefore, the current costs are not determined. The engineering hours are analysed for four different drawing packages. The planned engineering hours are 100, 90, 70, and 36 hours. The actual engineering hours are on the other hand 226.5, 153, 52, and 71 hours respectively. The difference in the planned and actual

[13] The information is obtained through one physically structured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging, one physically structured interview with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) and one physically unstructured interview with the Senior Production Engineer (39 years employed at Besi Netherlands Packaging).

engineering hours is significant. Besi Packaging has a hard time estimating the necessary hours to design a tool. The corresponding lead time for the drawing packages is 192, 408, 624 and 120 hours respectively.

3. Alternatives, criteria, and data generation

Based on the analysis conducted in Chapter 2, the possible Model-Based Definitions can be formulated. Chapter 3 contains the alternatives (possible Model-Based Definitions), criteria, and data generation. The chapter opens with Section 3.1 the alternatives (possible Model-Based Definitions). Thereafter, Section 3.2 contains the corresponding criteria of the alternatives (Model-Based Definitions). Chapter 3 concludes with Section 3.3 containing the corresponding scores of the alternatives (Model-Based Definitions) on the criteria.

3.1 Possible Model-Based Definitions (alternatives)

In this section the sub-question "*What are possible Model-Based Definitions for the T&F Engineering department of Besi Packaging*?" is answered. The possible Model-Based Definition contains the same product and manufacturing information, but the registration of the information is different. Therefore, the current information placed in the 2D drawing of the T&F Engineering department in Section 2.2 needs to be implemented in the possible Model-Based Definitions. When listing the possible Model-Based Definitions, this is considered.

The possible Model-Based Definitions (alternatives) consist of several elements. The elements of the possible Model-Based Definitions are listed and explained in Table 7 with the visual presentation in Figure 11. The Model-Based Definition elements consider the cross-departmental aspect of Model-Based Definition. Therefore, for the Combined states and Symmetrical dimensions, the added value is missing. The added value of the respective elements is for the production of the Production department, which is out of the scope of the research. (Refer Table 7 and Figure 11). [14]

Table 7 Explanation of the Single Possible Model-Based Definitions

Model-Based Definition elements	Explanation	Added value
Color coding	Color coding allows to indicate a difference between features (e.g. holes). The colour could represent a required operation step.	Prevents a lot of detailing.
Roughness & tolerances (update Besi table)	Design a concrete table with limited roughness and tolerances which can be used for defined purposes. The defined purposes are design construction.	Prevents a lot of detailing.
Form and Position tolerances	Geometric tolerances are indicated in the 3D model.	Prevents a lot of detailing.
Combined states (tabs on the bottom, Smart Annotate, and Smart Export)	Distinguishes between the operating steps with the tabs.	-
Symmetrical dimensions	Dimensions contain equally divided tolerances on both sides.	-

[14] The information is obtained through one physically structured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging, one physically structured interview with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) and one physically unstructured interview with the Senior Production Engineer (39 years employed at Besi Netherlands Packaging).

Model-Based Definition elements	Explanation	Added value
Template 110% model	The model is over-defined with features.	Prevents a lot of detailing.
Hole tables	The hole tables describe standard defined holes with the position indicated in x and y coordinates.	Prevents a lot of detailing.

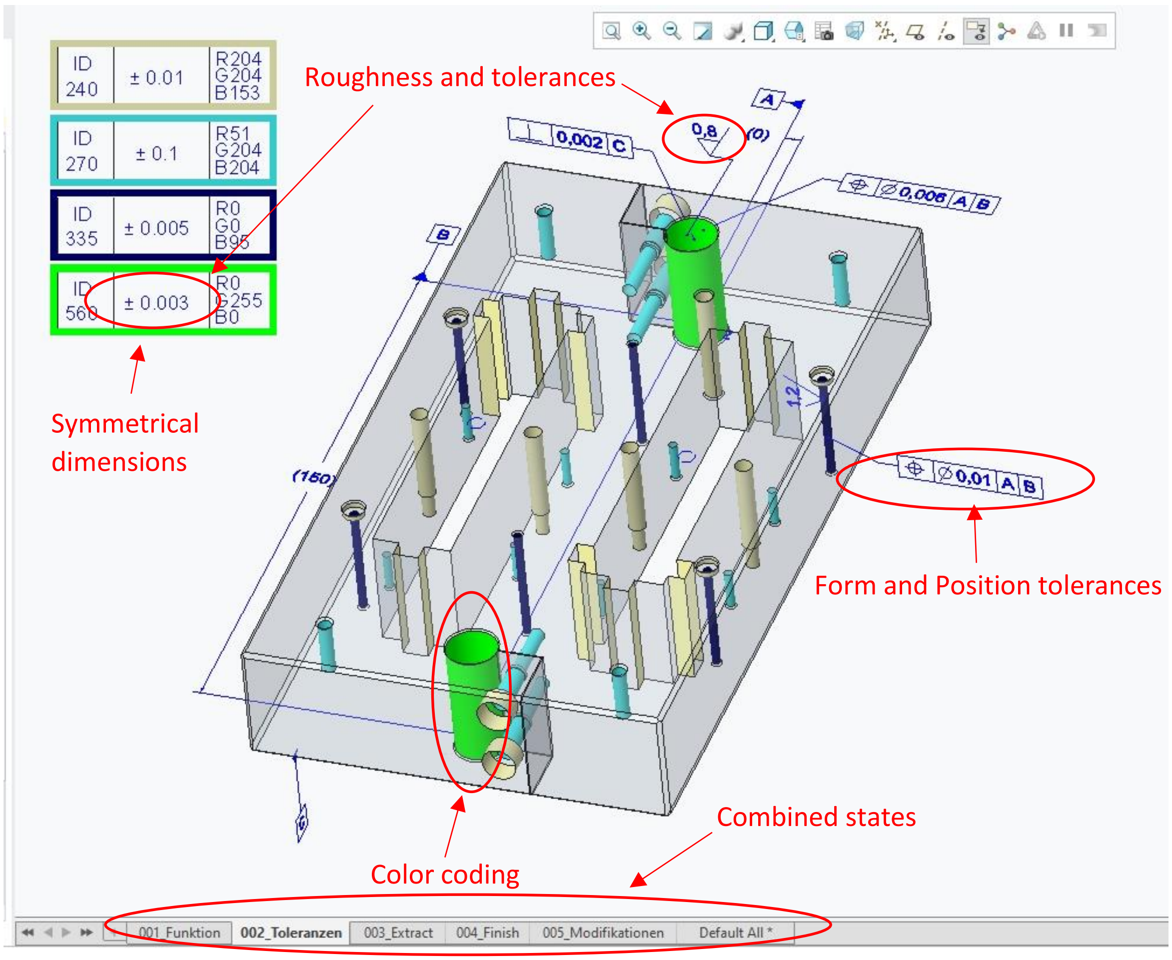


Figure 11 Model-Based Definition

The possible Model-Based Definitions consist of the elements presented in Table 7. The possible Model-Based Definitions are generated by the Mechanical Engineer (2 years employed at Besi Netherlands Packaging). The possible Model-Based Definitions are generated with solution combinations and maturity levels. Table 8 depicts the Model-Based Definitions with the corresponding elements (in random order of maturity and solution combination). The solution combinations are generated with themes of Model-Based Definition by the Mechanical Engineer. The research will not elaborate on the generation of the Mechanical Engineer.[15]

Table 8 Possible Model-Based Definitions Generation

	Solution combinations	Color coding	Roughness & tolerances (update Besi table)	Form and Position tolerances	Combined states (tabs on bottom, Smart Annotate, and Smart Export)	Symmetrical dimensions	Template 110% model	Hole tables
1	No other departments involved			X		X	X	
2	Knowledge upgrade T&F		X	X	X	X	X	X
3	No invest. costs, no smart export		X	X		X	X	X
4	Only 2D changes		X	X		X		X
5	Without production, only BESI NL	X	X	X		X	X	X
6	Internal improvement, within Mold& T&F Engineering department	X		X		X	X	X
7	All solutions	X	X	X	X	X	X	X

[14]

[15] The information is obtained through one physically structured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging, one physically structured interview with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) and one physically unstructured interview with the Senior Production Engineer (39 years employed at Besi Netherlands Packaging).

In Table 9 the possible Model-Based Definitions (alternatives) for the T&F Engineering department of Besi Packaging are shown in words. Table 9 depicts an overview of the alternatives and is equivalent to Table 8.[16]

Table 9 Possible Model-Based Definitions

Possible Model-Based Definition (alternatives)	Elements of the Model-Based Definition
MBD 1	Form and Position tolerances & Symmetrical dimensions & Template 110%
MBD 2	Roughness and tolerances (update Besi table) & Form and Position tolerances & Combined states (tabs on the bottom) & Symmetrical dimensions & Template 110% & Hole tables
MBD 3	Roughness and tolerances (update Besi table) & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables
MBD 4	Roughness and tolerances (update Besi table) & Form and Position tolerances & Symmetrical dimensions & Hole tables
MBD 5	Color coding & Roughness and tolerances (update Besi table) & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables
MBD 6	Color coding & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables
MBD 7	Color coding & Roughness and tolerances (update Besi table) & Form and Position tolerances & Combined states (tabs on the bottom) & Symmetrical dimensions & Template 110% & Hole tables

The possible Model-Based Definitions (total of 7 alternatives) presented in Table 9 will influence the current business flow of the T&F Engineering department (Chapter 2). The "change tool/forming layout to 3D (Creo)", "tool house modelling" and "the work 3D model out in detail to 2D drawing Creo" tasks of the business flow of the Trim & Form tool will be affected by working with any of the possible Model-Based Definitions (Refer Section 2.1).[17]

3.2 Criteria for the Model-Based Definition

In this section the sub-question *"What are the criteria of the Model-Based Definition for the T&F Engineering department of Besi Packaging?* " is answered.

As stated in Section 1.7.1, the AHP determines the optimal Model-Based Definition for the T&F Engineering department of Besi Packaging to reduce the engineering hours which is the goal of the research. To determine the optimal Model-Based Definition criteria are required. The AHP method

[16] The information was obtained through two physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) and the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) of the T&F Engineering department. Furthermore, the information was obtained through one online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software). The interviews were conducted separately, resulting in 3 conducted interviews.

[17] The information was obtained through physical semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) and the Senior Tool Developer (30+ years employed at Besi Netherlands Packaging). The interviews were conducted separately, resulting in 2 conducted interviews.

permits no overlap between the criteria. The requirement of the AHP method is considered in determining the criteria. The criteria are determined by the stakeholder, the management board of Besi Packaging since the management board of Besi Packaging is the decision maker.

The engineering hours [hours] are a required criterion to determine the optimal Model-Based Definition of the T&F Engineering department. The engineering hours are the average time an engineer requires to finish a tool. The average time to finish a tool consists of detailing, modelling, and checking the tool models (refer to Figure 6, Figure 7, Figure 8, and Figure 9 for the steps). In other words, the "change tool/forming layout to 3D (Creo)", "tool house modelling" and "the work 3D model out in detail to 2D drawing Creo" (refer Section 3.1) tasks of the business flow of the Trim & Form tool are part of the average time to finish a tool (engineering hours). The "change tool/forming layout to 3D (Creo)", "tool house modelling" and "the work 3D model out in detail to 2D drawing Creo" tasks of the business flow of the Trim & Form tool are part of the lead time as well. Therefore, the criteria engineering hours and lead time are overlapping. The engineering hours are a sub-part of the lead time. Overlap between the criteria is not permitted by the AHP. Therefore, the lead time is not considered as a criterion since the engineering hours cover the criterion. A reduction in engineering hours results in a reduction in the lead time.

Secondly, the costs [euros] are a required criterion to determine the optimal Model-Based Definition for the T&F Engineering department. The costs arising in the T&F Engineering department due to operating Model-Based Definition are supplementary software costs. The software costs consist of four licences (with a license the software package is bought), two-day training, and customized drawings (adjustments of the software for Besi Packaging). Thereafter, maintenance costs are the remaining yearly costs. In other words, the maintenance costs are the operational costs. Therefore, in the cost criterion, the segregation of investment costs and operational costs is attained. The segregation results in the criterion investment costs and the criterion operational costs. The operational costs are not related to the engineering hours, since the maintenance comes from the company providing the software. Moreover, the additional costs of implementing the Model-Based Definition and the engineering hours required to implement the Model-Based Definition are not considered due to the limited scope and time.[18]

The criteria to determine the optimal Model-Based Definition for the T&F Engineering department of Besi Packaging are demanded by the client Besi Packaging. Other criteria are not of interest to Besi Packaging. For example, ease of use is translated in the engineering hours criterion. [19]

3.3 Corresponding scores of the possible Model-Based Definitions on the criteria

In this section the sub-question "*What are the corresponding scores of possible Model-Based Definitions on the criteria for the T&F Engineering department of Besi Packaging?"* is answered based on the criteria determined in Section 3.2.

[18] The information was obtained through semi-structured interviews with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging) (physical interview), CEO B&W Software,(9 years employed at B&W Software) (online interview) and the Manager Project Engineering (22 years employed at Besi Netherlands Packaging) (physical interview). The interviews were conducted separately, resulting in 3 conducted interviews.

[19] The information was obtained through one physical semi-structured interviews with the Project Manager Engineering (22 years employed at Besi Netherlands Packaging). The Project Manager Engineering retrieved the information from the Senior Vice President Packaging (25 years employed at Besi Netherlands Packaging) to verify if the criteria correspond to the demand of the Besi management board.

The investment costs criterion

The investment costs criterion consists of four floating licenses (with a license the software package is bought), a two-day training, and customized drawings (adjustments of the software for Besi Packaging). Four floating licenses are sufficient for the Trim & Form Engineering department (twelve engineers in total, six in Europe & six in Asia). The four licenses cost 10800 euros. In the occurrence of the purchase of a licence, the license is permanently owned. The two-day training costs are 1800 euros. Furthermore, the customized drawings cost 2700 euros. The software packages of interest are Smart Color, Smart Annotate, and Smart Export. For MBD 7 the three software packages are required. MBD 5 and MBD 6 require color coding, i.e., Smart Color. MBD 2 requires Combined states, i.e., the Smart Annotate and Smart Export. The investment costs are depicted in Table 10. An assumption in Table 10 is that the software packages have approximately the same costs (Refer Table 10). [20]

Table 10 Investment Costs

Software package with four licenses	Investment costs [euros]
Smart Annotate and Smart Export	10800+1800+2700=15300 (single software package) 15300*2=30600 (two software packages)
Smart Color	15300 (single software package)
Smart Annotate, Smart Export, and Smart color	30600+15300=45900 (three software packages)

The operational costs criterion

The operational costs criterion consists of the maintenance costs. In Table 11 the investment costs criterion and the operational costs criterion with the corresponding Model-Based Definitions are depicted. The costs consider the new costs when implementing a Model-Based Definition, the current costs remain (Refer Section 2.3). Moreover, the investment costs and operational costs are spread over 5 years. The Besi management board demands the earning back of the costs within 5 years. [21]

[20] The information was obtained through comparable previously bought software packages by Besi Netherlands Packaging. Two comparable quotes were used. Moreover, the online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software) served as input. The information was obtained through one physical semi-structured interview with CAD/PLM Application Manager (27 years employed at Besi Netherlands Packaging)

[21] The information was obtained through one physical semi-structured interviews with the Project Manager Engineering (22 years employed at Besi Netherlands Packaging). The Project Manager Engineering retrieved the information from the Senior Vice President Packaging (25 years employed at Besi Netherlands Packaging) to verify if the criteria correspond to the demand of the Besi management board.

Table 11 Investment Costs and Operational Costs with Corresponding Model-Based Definition

Possible Model-Based Definition	Required software packages	Investment costs [euros]	Operational costs [euros]
MBD 1	Current software	0	0
MBD 2	Smart Annotate and Smart Export	30600	1800*2= 3600
MBD 3	Current software	0	0
MBD 4	Current software	0	0
MBD 5	Smart color	15300	1800
MBD 6	Smart color	15300	1800
MBD 7	Smart Annotate, Smart Export, and Smart color	45900	1800*3= 5400

The engineering hours criterion

The average time an engineer requires for detailing the 2D drawing is 7.30 hours. Implementing the most advanced version of the Model-Based Definition results in a reduction of 50% in detailing. Chapter 2 presented the location of the core problem, namely "work 3D model out in detail on a 2D drawing". Therefore, the reduction of detailing caused by operating Model-Based Definition corresponds to tackling the core problem. The reduction is among other things caused by the automatically applied rules for the features that have the corresponding name in the 3D model. This function is specifically for the B&W Software software. An example of the function is presented in Figure 12.[22]

[22] The information was obtained through comparable previously bought software packages by Besi Netherlands Packaging. Two comparable quotes were used. Moreover, the online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software) served as input. The information was obtained through one physical semi-structured interview with CAD/PLM Application Manager (27 years employed at Besi Netherlands Packaging)

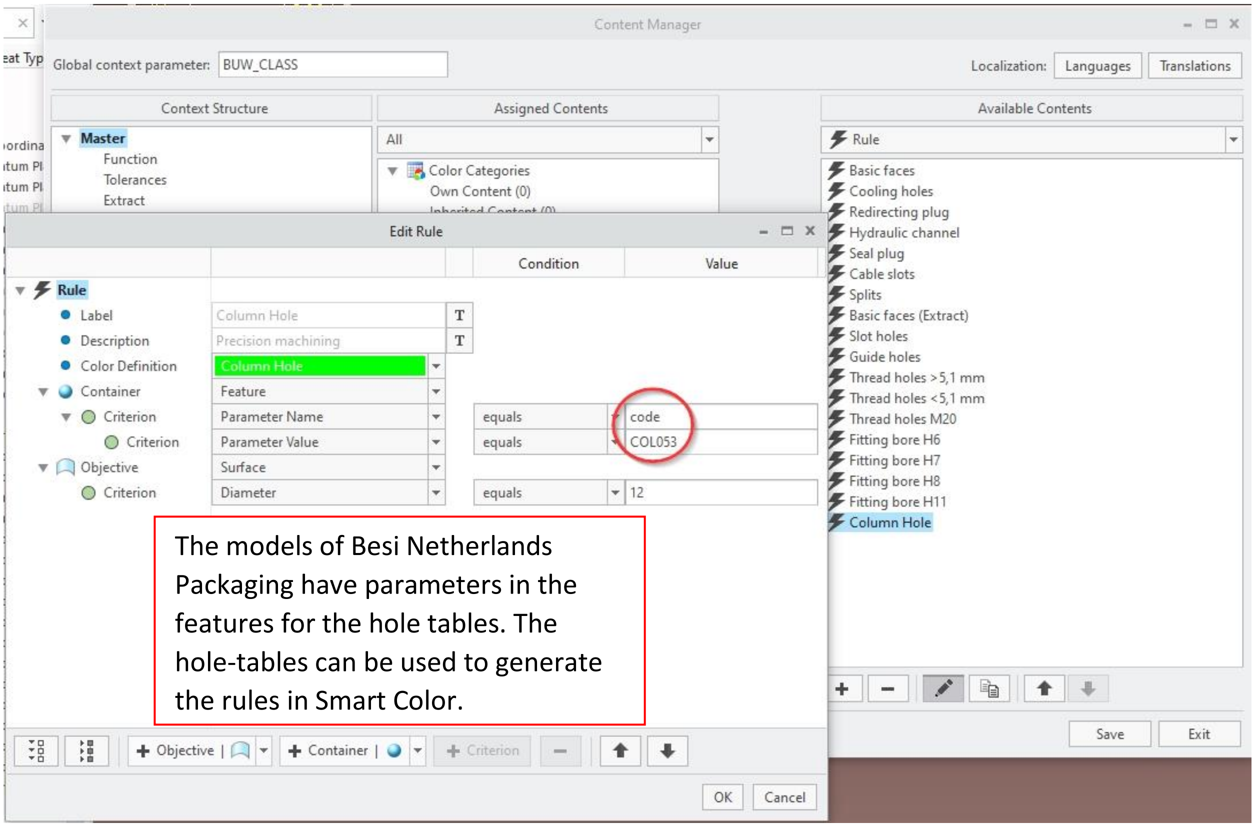


Figure 12 Rules for Features

Therefore, the detailing time of engineering will reduce by $7.30 * 0.5 = 3.65$ hours per drawing package when implementing the most advanced version of Model-Based Definition.[23]

The average of the planned engineering hours in Table 3, Table 4, Table 5, and Table 6 is $\frac{100+90+70+36}{4} = 74$ hours. The average of the actual engineering hours in Table 3, Table 4, Table 5, and Table 6 is $\frac{226.5+153+52+71}{4} = 125.625$ hours. The average of the planned and actual engineering hours in Table 3, Table 4, Table 5, and Table 6 resulted in $\frac{74+125.625}{2} = 99.8125 \approx 100$ engineering hours. Therefore, the most advantageous Model-Based Definition (MBD 7) will have $100 - 7.30 * 0.5 = 96.35$ engineering hours.

Factors are assigned to the possible Model-Based Definitions by the Mechanical Engineer (2 years employed at Besi Packaging) to measure the elements of the Model-Based Definitions considering the engineering hours criterion. The maximum score is a 9 and corresponds to the most advanced Model-Based Definition.[2] Therefore, the rate of the factor results in $\frac{100-96.35}{9} = \frac{73}{180} \approx 0.41$ engineering hours

[23] The information was obtained through the online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software). Moreover, the engineering time for detailing the 2D drawing was required by two physical and two online structured interviews with the four engineers of the four drawing packages. The engineer corresponding to the drawing package delivered the time consumed for detailing the 2D part drawings.

reduction per factor score 1. For example, when implementing MBD with a factor score of 4, the reduction in engineering hours is $\frac{73}{180} * 4 \approx 1.62$ hours of the total 100 engineering hours required per tool.

The factors corresponding to the possible Model-Based Definitions are determined by assigning weights to every Model-Based Definition element and are shown in Table 12. The factors are assigned by the Mechanical Engineer (2 years employed at Besi Packaging). The values in Table 12 are approximations (Refer Table 12).[24]

Table 12 The Single Model-Based Definitions with Corresponding Factors

	Relevant Model-Based Definitions						
	Color coding	Roughness & tolerances, update Besi table	Form and Position tolerances	Combined states (tabs on bottom, Smart Annotate and Smart Export)	Symmetrical dimensions	Template 110% model	Hole tables
Factors	1	1	1.5	1.5	1	1.5	1.5

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Thereafter, the Model-Based Definitions scores can be determined. The Model-Based Definitions factor scores are determined with Table 8 and Table 12. In Table 13 the factor scores of the Model-Based Definitions are depicted (Refer Table 13).

Table 13 The Model-Based Definitions with Corresponding Factor Score

Model-Based Definitions		Factor scores
MBD 1	Form and Position tolerances & Symmetrical dimensions & Template 110%	4
MBD 2	Roughness and tolerances, update Besi table & Form and Position tolerances & Combined states (tabs on bottom)& Symmetrical dimensions & Template 110% & Hole tables	8
MBD 3	Roughness and tolerances, update Besi table & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables	6.5
MBD 4	Roughness and tolerances, update Besi table & Form and Position tolerances & Symmetrical dimensions & Hole tables	5
MBD 5	Color coding & Roughness and tolerances, update Besi table & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables	7.5
MBD 6	Color coding & Form and Position tolerances & Symmetrical dimensions & Template 110% & Hole tables	6.5
MBD 7	Color coding & Roughness and tolerances, update Besi table & Form and Position tolerances & Combined states (tabs on the bottom, focused on production steps) & Symmetrical dimensions & Template 110% & Hole tables	9

[24] The information was obtained using Section 2.3 as fundaments for the approximation. Previously purchased comparable software packages bought by Besi Netherlands Packaging and the online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software) served as input.

[25]

Thereafter, the average engineering hours for the possible Model-Based Definitions can be determined with Table 13. The current engineering hours per tool (100 hours) are used. On top of that, the reduction factor $\frac{73}{180}$ and the corresponding factor score in Table 13 resulted in Table 14 (Refer Table 14).

Table 14 The Engineering Hours and Lead Time for the Corresponding Model-Based Definition

Possible Model-Based Definition	Factor	Average engineering hours with MBD	Average lead time with MBD
MBD 1	4	$100 - \frac{73}{180} * 4 \approx 98.38$	The same reduction as engineering hours
MBD 2	8	$100 - \frac{73}{180} * 8 \approx 96.76$	The same reduction as engineering hours
MBD 3	6.5	$100 - \frac{73}{180} * 6.5 \approx 97.36$	The same reduction as engineering hours
MBD 4	5	$100 - \frac{73}{180} * 5 \approx 97.97$	The same reduction as engineering hours
MBD 5	7.5	$100 - \frac{73}{180} * 7.5 \approx 96.96$	The same reduction as engineering hours
MBD 6	6.5	$100 - \frac{73}{180} * 6.5 \approx 97.36$	The same reduction as engineering hours
MBD 7	9	$100 - \frac{73}{180} * 9 \approx 96.35$	The same reduction as engineering hours

In Table 15 the corresponding values of the criteria for the possible Model-Based Definitions (alternatives) for the T&F Engineering department of Besi Packaging are depicted to provide an overview.

[25] The information is obtained through one physically structured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging, one physically structured interview with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging) and one physically unstructured interview with the Senior Production Engineer (39 years employed at Besi Netherlands Packaging).

Table 15 Corresponding Criteria for the Model-Based Definitions

Possible Model-Based Definition	Engineering hours [hours]	Investment costs [euros]	Operational costs [euros]
MBD 1	98.38	0	0
MBD 2	96.76	30600	3600
MBD 3	97.36	0	0
MBD 4	97.97	0	0
MBD 5	96.96	15300	1800
MBD 6	97.36	15300	1800
MBD 7	96.35	45900	5400

3.4 Conclusion

The main findings of Chapter 3 are the possible Model-Based Definitions for the T&F Engineering department. Seven relevant possible Model-Based Definitions for the T&F Engineering department of Besi Packaging exist (Refer Table 9). The Model-Based Definition will not change the product and manufacturing information, only the way of registering the data will be different.

Furthermore, the criteria that are important to determine the optimal Model-Based Definition and function as input for the analytical hierarchy process are the engineering hours [hours], investment costs [euros], and operational costs [euros]. The engineering hours are the average time an engineer requires to finish a tool. The average time to finish a tool consists of detailing, modelling, and checking the tool models. The costs [euros] consider the new costs that occur when implementing a Model-Based Definition. The new costs for the Trim & Form Engineering department are investment costs and operational costs. The investment costs contain the four floating licenses, two-day training, and customized drawings. The operational costs contain the yearly maintenance costs.

The criteria mentioned are important to the Besi Packaging managing board. Other criteria are not of interest to Besi Packaging.

The corresponding values of the criteria concerning the possible Model-Based Definitions are presented in Table 15 (Refer Table 15).

4. Solution choice

Chapter 4 starts with an explanation of the analytical hierarchy process steps in Section 4.1. Thereafter, Section 4.2 applies the analytical hierarchy process to determine the optimal Model-Based Definition. Chapter 4 concludes with Section 4.3 the optimal Model-Based Definition to reduce engineering hours in the T&F Engineering department. In Section 4.3 the main research question is answered.

4.1 Analytical hierarchy process explanation

The problem has criteria with different weights. In addition, alternatives score differently on the criteria. The most attractive alternative is found via a weighted average. In this section, the analytical hierarchy process calculations are explained. The section is divided into "achieving weights for the criteria", "Consistency check", and "Scores of the alternatives for the criteria".

Achieving weights for the criteria

Thomas Saaty provided the analytical hierarchy process to choose between alternatives. The alternatives must meet a few criteria. The analytical hierarchy process starts with designing the Pairwise Comparison Matrix. The Pairwise Comparison Matrix (A) consists of the importance of the criteria in proportion to the other criteria presented by a_{ij}. a_{ij} presents the importance of the entry of row i of the Pairwise Comparison Matrix compared to column j of the Pairwise Comparison Matrix. The decision maker determines the importance of the proportions of the criteria with the Saaty scale (Refer Table 16) *(Winston & Goldberg, 2004) (Manoj Mathew, 2018).*

Table 16 The Saaty Scale (Interpretation of Entries in the Pairwise Comparison Matrix)

Value a_{ij}	Interpretation of importance
1	Equal importance (i and j are equally important)
3	Moderate importance (i is slightly more important than j)
5	Strong importance (i is strongly more important than j)
7	Very strong importance (i is very strongly more important than j)
9	Extreme importance (i is absolutely more important than j)
2,4,5,6,8	Intermediate values
	1/3, 1/5, etc. values for inverse comparison

Furthermore, the Normalised Pairwise Comparison Matrix is generated. The Normalized Pairwise Comparison Matrix (A_{norm}) is generated by dividing the entry of Matrix A by the sum of the corresponding column. The sum of the column of the A_{norm} Matrix is 1. Thereafter, the criteria weight w_i is determined. The criteria weight is retrieved by the sum of the row of Matrix A_{norm} divided by n (the number of criteria). The criteria weights result in vector **w**. *(Winston & Goldberg, 2004) (Manoj Mathew, 2018)*

Consistency check

Thereafter, the consistency of the Pairwise Comparison Matrix is checked. The check of the consistency of the Pairwise Comparison Matrix A starts with calculating A***w**.

On top of that, λ_{max} is determined with the following formula $\lambda_{max} = \frac{\sum_{i=1}^{i=n} \frac{(A*w)_i}{w_i}}{n}$

Furthermore, the consistency index (CI) is calculated in the following way $CI = \frac{\lambda_{max} - n}{n-1}$

The number of criteria n is searched in Table 17, thereby the Random Index (RI) is retrieved.

Table 17 Random Index (RI)

n	RI
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.51

At last, for the consistency, the consistency ratio is determined with the RI retrieved from Table 7 and the calculated CI. The consistency ratio ($CR = \frac{CI}{RI}$) states that the Pairwise comparison Matrix A is consistent if $\frac{CI}{RI} < 0.10$ *(Winston & Goldberg, 2004) (Manoj Mathew, 2018).*

Scores of the alternatives for the criteria

Generate for every single criterion a Pairwise Comparison Matrix with in the rows and columns the alternatives. Thereafter, generate for the Pairwise Comparison Matrix the Normalized Pairwise Comparison Matrix for each criterion. The same procedure is performed as mentioned before (the criteria weight) to determine in this case the alternative score.

At last, to determine the best alternative, the overall score of the alternative is determined. The criteria weights multiplied with the alternative score on the criteria summed is the overall score of an alternative.

$$\text{score } j = \sum_{i=1}^{i=n} w_i * \text{score}_{ij}$$

$$\text{where score}_{ij} = \text{normalized score of alternative j on criterion i}$$

$$\text{score } j = \text{final score alternative i}$$

$$w_i = \text{weight criterion i}$$

The alternative with the highest score is the best alternative *(Winston & Goldberg, 2004).*

4.2 Applied analytical hierarchy process to determine the optimal Model-Based Definition

The information in Chapter 3 functions as the input for the steps described in Section 4.1 to perform the analytical hierarchy process calculations. In this section the analytical hierarchy process calculations are performed.

Achieving weights for the criteria

At first, the Pairwise Comparison Matrix A considering the criteria is generated with Table 16 in Table 18.[26]

Table 18 Pairwise Comparison Matrix A Criteria

	Engineering hours	Investment costs	Operational costs
Engineering hours	1	7	9
Investment costs	0.143	1	3
Operational costs	0.111	0.333	1
Sum	1.254	8.333	13

Thereafter, the Normalized Pairwise Comparison Matrix A_{norm} is generated and the criteria weights w_i are determined. The Normalized Pairwise Comparison Matrix is generated by dividing the entry of the Pairwise Comparison Matrix by the sum of the column. The sum of the Normalized Pairwise Comparison Matrix column is equal to 1. The criteria weights are calculated by summing the row of the Normalized Pairwise Comparison matrix. The criteria weights result in vector **w** (Refer Table 19).

Table 19 Normalized Pairwise Comparison Matrix Criteria

	Engineering hours	Investment costs	Operational costs	Criteria weights (w_i) **w**
Engineering hours	0.797	0.84	0.692	0.777
Investment costs	0.114	0.12	0.231	0.155
Operational costs	0.089	0.04	0.077	0.069
Sum	1	1	1	

Consistency check

Thereafter, the consistency of the Pairwise Comparison Matrix is checked. The check starts with calculating A***w**. In Table 20 the last column is calculated by dividing the sum by the criteria weight (w_i) to result in A***w** easily.

[26] The information was obtained through a physical semi-structured interview with the Manager Project Engineering (22 years employed at Besi Netherlands Packaging). The Manager Project Engineering went in consultation with the Senior Vice President Packaging (25 years employed at Besi Netherlands Packaging). The outcome resulted in the criteria "importance".

*Table 20 A****w***

	Engineering hours*w_1	Investment costs*w_2	Operational costs*w_3	The sum of the row	A***w**
Engineering hours	0.777	1.084	0.617	2.477	3.190
Investment costs	0.111	0.155	0.206	0.471	3.043
Operational costs	0.086	0.052	0.069	0.206	3.013

$\lambda_{\max} = \frac{\sum_{i=1}^{i=n} \frac{(A*\mathbf{w})_i}{w_i}}{n}$ is calculated with n= 3 since there are 3 criteria. From Table 17 corresponding RI is 0.58. The information stated above resulted in Table 21 (Refer Table 21).

Table 21 Consistency Check

λ_{max}	3.082
Consistency Index (C.I.)	0.041
Random Index (R.I.)	0.58
Consistency Ratio	0.072
If Consistency Ratio is <0.10, then outcome is valid	Consistent

Scores of the alternatives for the criteria

Thereafter, the same steps are performed for the alternatives. The scores of the alternatives are determined per criterion. Table 16 is used to score the alternatives. Furthermore, the same steps are performed as mentioned in the analytical hierarchy process explanation (Refer the appendix).

The performed steps in the appendix resulted in Table 22 depicting the scores of the alternatives on the criteria and the overall score of the alternatives. The criteria weights and the scores of the alternatives for the criteria resulted in the overall score of the Model-Based Definitions.

$$\text{score j} = \sum_{i=1}^{i=n} w_i * \text{score}_{ij}$$

The Model-Based Definition with the highest score is the best alternative. Table 22 depicts the highest score for MBD 7. Therefore, MBD 7 is the optimal Model-Based Definition to reduce engineering hours.

Table 22 Scores of the Alternatives for the Criteria and the Overall Score

	Engineering hours (w_1=0.777)	Investment costs (w_2=0.155)	Operational costs (w_3=0.069)	Overall score
MBD 1	0.027	0.199	0.181	0.064
MBD 2	0.213	0.080	0.098	0.185
MBD 3	0.096	0.199	0.181	0.118
MBD 4	0.041	0.199	0.181	0.075
MBD 5	0.166	0.136	0.147	0.160
MBD 6	0.096	0.136	0.147	0.106
MBD 7	0.361	0.050	0.065	0.293

4.3 Conclusion: The optimal Model-Based Definition to reduce engineering hours in the T&F Engineering department

In this section the sub-question "*What is the optimal Model-Based Definition to reduce engineering hours for the T&F Engineering department of Besi?*" is answered.

The analytical hierarchy process resulted in the highest score for Model-Based Definition 7. Model-Based Definition 7 contains "Color coding & Roughness and tolerances (update Besi table) & Form and Position tolerances & Combined states (tabs on the bottom) & Symmetrical dimensions & Template 110% & Hole tables". The corresponding engineering hours, investment costs, and operational costs are 96.35 hours, 45900 euros, and 5400 euros respectively. Therefore, the reduction of engineering hours is $\frac{100-96.35}{100} * 100 = 3.65\%$.

Furthermore, the corresponding ROI of the optimal Model-Based Definition must be spread over 5 years according to the Besi management board. The ROI calculation starts with determining the costs of the engineers in Malaysia and the Netherlands. The engineers in the Netherlands and Malaysia cost 67 euros per hour and 24 euros per hour respectively. In the Netherlands six engineers are employed and six engineers are employed in Malaysia. Therefore, the average price per engineer is $\frac{67 + 24}{2} = 45.50$ euros per hour.

Furthermore, the investment costs and the operational costs over 5 years sum to 45900 (investment) + 5400 * 5 (operational) = 72900 euros (Refer Table 15). Per year the total costs are $\frac{72900}{5} = 14580$ euros per year. To earn back the costs $\frac{14580 \text{ (total costs per year)}}{45.50 \text{ (costs per engineer per hour)}} \approx 320.44$ hours per year need to be saved. On average an engineer works 1650 hours per year *(1650 UUR - INTERIMDIENSTEN.com, n.d.)*. Therefore, a $\frac{320.44}{1650*12} * 100 \approx 1.62$ % reduction of total engineering hours per year is required. Since the realised reduction of the optimal Model-Based Definition is 3.65%, the ROI is met.

Moreover, the actual ROI is calculated. The $\text{ROI} = \frac{\text{Net yield}}{\text{Total costs}} * 100\%$. The net yield of working with the Model-Based Definition is (the reduction of engineering hours) * (the labour costs per hour per engineer) * (the number of engineers) * (the total hours an engineer works per year) – (total costs). Therefore,

$\text{ROI} = \frac{\text{Net yield}}{\text{Total costs}} * 100\% = \frac{(0.0365*45.5*12*1650 - 14850)}{14850} * 100 \approx 121.43\%$. Remark, the costs hours of the T&F engineers that are required to implement a Model-Based Definition are not considered, due to the limited scope and time. The limitation explains the high ROI. Due to the money range of the Model-Based Definitions investment- and operational costs, no alternative was unfeasible. [27]

[27] The information was obtained through one physical semi-structured interview with the Manager Project Engineering (22 years employed at Besi Netherlands Packaging).

5. Conclusions and recommendations

Chapter 5 starts with the answers to the research questions in Section 5.1. Furthermore, in Section 5.2 the recommendations to Besi Packaging are explained. Moreover, the discussion is depicted in Section 5.3. Section 5.4 contains the limitations of the research. Chapter 5 concludes with Section 5.5 presenting the future scope.

5.1 Answers to the research questions

"What is the current business flow of a tool in the T&F Engineering department of Besi Packaging?"

The current business flow of a tool in the T&F Engineering department of Besi starts with a customer order arriving. Thereafter, the engineer starts designing the tool/forming layout in 2D. Subsequently, the tool/forming layout in 2D is changed to 3D. The tool house model is designed after the tool/forming layout in 3D. The design review document and the internal discussion are the following tasks. The 3D model is worked out in detail on 2D drawing and goes through the checklist. After finishing all the tasks, the files are transported to Agile. In other words, transferred to the Supply Chain department. If steps in the process were not sufficient, a return in the process is performed. The core problem is depicted in the step "work 3D model out in detail on a 2D drawing". Therefore, working with a Model-Based Definition will have the most impact on working the 3D model out in detail on a 2D drawing.

"What information is currently placed in a 2D drawing of the T&F Engineering department of Besi Packaging?"

The current situation is analysed with four standard drawing packages of the Trim & Form Engineering department. The four drawing packages are the Dambar Cutting tool, the Forming tool, the Final Cutting tool, and the Separating tool. The analysis resulted in the information currently placed in a 2D drawing. The information currently placed in a 2D drawing is the tool part material, the specific production treatment, the dimensional tolerances, the geometric tolerances, the ordinate dimensions, the hole tables, roughness, and remarks. The Model-Based Definition contains the same product and manufacturing information, but the way of presenting the information is different.

"What are the current costs, lead time, and engineering hours in the T&F Engineering department of Besi Packaging?"

The Dambar cutting tool, the Forming tool, the Final cutting tool, and the Separating tool have planned engineering hours of 100 hours, 90 hours, 70 hours, and 36 hours respectively. The actual engineering hours are 226.5 hours, 153 hours, 52 hours, and 71 hours respectively. The total amount of lead time is respectively 8 days, 17 days, 26 days, and 5 days. The current costs remain in the T&F Engineering department, therefore the current costs are perceived as is. The planned engineering hours and actual engineering hours are far apart.

"What are possible Model-Based Definitions for the T&F Engineering department of Besi Packaging?"

The possible Model-Based Definitions for the T&F Engineering department of Besi Packaging consist of seven possibilities. The seven possible Model-Based Definitions for the T&F Engineering department of Besi are presented in Table 9 (Refer Table 9). The global differences between the Model-Based Definition are the different elements a Model-Based Definition. The different elements of the Model-Based

Definitions are presented in Table 7 (Refer Table 7). The different elements of the Model-Based Definitions are assigned with the solution combinations presented in Table 8 (Refer Table 8).

"What are the criteria of the Model-Based Definition for the T&F Engineering department of Besi Packaging?"

The engineering hours [hours], investment costs [euros], and operational costs [euros] are the criteria of the Model-Based Definition for the T&F Engineering department of Besi Packaging. The engineering hours are the average time an engineer requires to finish a tool. The average time to finish a tool consists of detailing, modelling, and checking the tool models. The costs arising in the T&F Engineering department due to operating Model-Based Definition are supplementary software costs. The software costs consist of floating licenses (with a license the software package is bought), two-day training, and customized drawings (adjustments of the software for Besi). Thereafter, maintenance costs are the remaining yearly costs. In other words, the maintenance costs are the operational costs Therefore, in the cost criterion, the segregation of investment costs and operational costs is attained. The lead time is not a criterion to determine the optimal Model-Based Definition since the lead time contains the engineering hours. Moreover, the lead time will only change considering the engineering hours. On top of that, the analytical hierarchy process does not allow an overlap between the criteria.

"What are the corresponding scores on the criteria for possible Model-Based Definitions for the T&F Engineering department of Besi Packaging?"

The corresponding scores on the criteria for the possible Model-Based Definitions for the T&F Engineering department of Besi Packaging are presented in Table 15 (Refer Table 15).

"What is the optimal Model-Based Definition to reduce engineering hours for the T&F Engineering department of Besi Packaging?"

The optimal Model-Based Definition to reduce engineering hours in the T&F Engineering department is MBD 7. MBD 7 contains "Color coding & Roughness and tolerances (update Besi table) & Form and Position tolerances & Combined states (tabs on the bottom) & Symmetrical dimensions & Template 110% & Hole tables". The engineering hours corresponding to the optimal Model-Based Definition is 96.35 hours. The new engineering hours contain a reduction of 3.65% compared to the current engineering hours. The investment cost and operational costs are 45900 euros and 5400 euros per year (over 5 years) respectively. The ROI of the optimal Model-Based Definition is 121.43%.

5.2 Recommendations

The optimal Model-Based Definition results in a reduction of 3.65% of engineering hours per tool. The required reduction of engineering hours to earn back the investment is 1.62% of the total engineering hours. The reduction of engineering hours is the goal for Besi Packaging, therefore Model-Based Definition is recommended. Furthermore, the risk of not earning back the investment- and operational costs is low since the ROI is 121.43% spread over 5 years. Therefore, the Model-Based Definition is promising for the Trim & Form Engineering department of Besi Packaging. On the other hand, investigation is required for the consequences of the Production- and Quality Control department of Besi Packaging for implementing a Model-Based Definition. Section 5.5 elaborates on the future scope.

Furthermore, the research showed a significant difference between the planned engineering hours and the actual engineering hours. For Besi Packaging the recommendation is to reduce the significant difference to be able to design more accurate schedules for the micro planning.

5.3 Discussion

The estimation for the new engineering hours corresponding to the optimal Model-Based Definition is hard. The difference between the scheduled engineering hours and planned engineering hours presented in Table 15 depicts the difficulty in estimating the new engineering hours. On top of that, the four different engineers of the analysed drawing packages estimated the time to detail the drawing packages. A drawing package consists of significant amount of part drawings. The four engineers were asked to provide the estimated time per drawing package and for all the corresponding part drawings. The sum of the estimation of the part drawings should be equal to the entire drawing package estimation. On average the estimation of the entire drawing package (30 hours) was four times bigger than the average sum of the estimations per drawing part (7.30 hours). This indicates the difficulty of the estimation of the engineering hours.

Moreover, the four drawing packages chosen for the analysis of the 2D drawings were designed with the use of a similar existing tool. Therefore, the detailing hours are lower in comparison to designing a new tool. In other words, the optimal Model-Based Definition could reduce the engineering hours more when designing a new tool that does not have similar existing tool models.

Therefore, due to the estimation difficulty of the new engineering hours and the use of a tool that had a similar existing design, the engineering hours reduction is the minimal expected reduction. MBD 7 reduces the detailing time for 2D drawings with 50%. The research showed that the detailing time for 2D drawings is approximately between 7.30 hours and 30 hours. Therefore, the detailing time is a bigger part of the engineering hours than calculated with in the research. That is, the research calculated the reduced engineering hours percentage with the 7.3 hours of detailing which is lower compared to reality. Moreover, as soon as a similar tool does not exist, the detailing hours of 2D drawings will be higher. Which results in a higher reduction of engineering hours. Therefore, the engineering hours reduction of 3.65% is the minimal reduction.

Moreover, whilst listing Table 7 the cross-departmental effect of Model-Based Definition is considered. The reduced scope resulted in the exclusion of the Production department in the research. For listing Table 7 the exclusion of the Production department was impossible. Therefore, the Senior Production Engineer provided input to generate the elements of the Model-Based Definitions (Table 7).

Furthermore, an assumption that is made is the merger of the engineers in Malaysia and the Netherlands to calculate the engineering costs. In the Netherlands, more experts are working who work on special tools. The standard tools are designed in Malaysia. On top of that, the labour costs are lower in Malaysia compared to the Netherlands. Therefore, the equal split between the labour costs of Malaysian engineers and the Netherlands engineers calculation does not fully represents the reality.

Implementing a Model-Based Definition will require time of the engineers to record agreements regarding the product and manufacturing information. The research did not take the time of the engineers to record agreements regarding the product and manufacturing information into consideration. The required time to record agreements regarding the product and manufacturing information will result in additional costs when implementing the Model-Based Definition in the T&F Engineering department of Besi Packaging. In Section 5.5 an elaboration for the future scope is presented.

On the other hand, the problem - and improvement points within the Trim & Form Engineering department are made comprehensible. Therefore, despite the uncertainty factors in the research, the set-up of the research can be used in future decision-making regarding Model-Based Definition within Besi.

5.4 Limitations

The limitation of the research is the reduced scope. The scope of the research is reduced drastically compared to the wide impact of the Model-Based Definition. Therefore, when utilizing the results of the research, the reduced scope needs to be considered. The Production (including work preparation) – and Quality Control department(s) result in additional costs and benefits. An example of the additional benefits is the reduction of the number of mistakes in the production of the Production department. Less mistakes will result in a lower lead time and less material costs. Concerning material costs, expensive hardened metals are used. A reduction in material costs will be advantageous. Moreover, production can produce faster when the Model-Based Definition contains the CAD-CAM coupling. Working with the Model-Based Definition results in less effort from the work preparator in the Production department. Therefore, Model-Based Definition results in more efficient work preparation. On the other hand, the Production department contains old machines. The old machines cannot work with the CAD-CAM coupling. Therefore, new machines must be purchased. Furthermore, the suppliers of outsourced production parts of Besi Packaging might not be able to work with the Model-Based Definition way of delivering the product and manufacturing information. Therefore, new suppliers might be needed to consider or a coupling to the current way of working is required. Due to the reduced scope, this is not considered in the research which is a limitation of the research.[28]

5.5 Future scope

In general, further investigation of Model-Based Definitions in the Engineering, Production, and Quality control departments is recommended for Besi Packaging. Presenting the product and manufacturing information in a different way has an impact on the departments, respectively, since the Model-Based Definition has the strength to have cross-departmental benefits/impacts. Implementing the Model-Based Definition within Besi Packaging will take years. The implementation time needs to be considered.

[28] The information was obtained through one online unstructured interview with the Senior Production Engineer (39 years employed at Besi Netherlands Packaging).

The Production department

An investigation is required in the Production department on the optimal Model-Based Definition consequences. Specific points for the Production department are highlighted below.

- The production of Production department will have less paperwork when operating with the optimal Model-Based Definition. The consequence is every machine must contain a display where the 3D models can be retrieved and zoomed in. E.g., color coding presents a tolerance, but the dimensions are not shown. On the other hand, the 3D model can be turned to show the hidden holes. Therefore, the Production department needs to conduct research on the manually performed operations and the possible changes to the CAD-CAM coupling. Currently, wire EDM, electrode milling, and normal milling contain CAD-CAM coupling, whilst grinding is performed manually. For grinding a manual program is generated to fabricate the tool part. Therefore, further research needs to be conducted to assure that the 3D model generated with the optimal Model-Based Definition contains all the necessary information for the production of the Production department. The optimal Model-Based Definition assumes that the production of the Production department is in possession of machinery that automatically read a 3D file and generate the product. The production of the Production department contains currently old machines, so new machines might be required. An investigation regarding this topic is recommended.[29]
- Another aspect for further investigation is the intelligence of the CAM software package in the production of the Production department. For example, a hole can require several operating steps in the production of the Production department. For example, H7 requires centring, drilling, and reaming. The CAM software should identify and thereafter signal the machine to perform the additional required operating steps. For example, Solidworks CAM contains the intelligent CAM software package. If the Master CAM contains the intelligent CAM software is unknown to Besi Packaging. Further investigation is required. [29]
- Moreover, the suppliers of Besi will be impacted due to the delivery of different 3D models. Therefore, an investigation of the different suppliers and the consequences of MBD need to be investigated.

Quality Control department

Furthermore, the Quality Control department needs the correct software to make use of the 3D model generated by the optimal Model-Based Definition. Besi Leshan (Malaysia) is currently busy with new software for the Quality Control department. Further investigation is recommended whether the software can be used to work with the optimal Model-Based Definition or if other software is required. In the case of other required software, the other software must be investigated. [29]

[29] The information was obtained using Section 2.3 as fundaments for the approximation. Previously purchased comparable software packages bought by Besi Netherlands Packaging and the online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software) served as input.

Trim & Form Engineering department

On top of that, the recommendation for the future scope is to start implementing the Model-Based Definition at present slowly in the company and start at the Trim & Form Engineering department. The Trim & Form engineers should get time to start making agreements to standardize tools and measurements which is possible with the elaborated analysis of the 2D drawings in the appendix. On top of that, B&W Software provided licenses to test the Model-Based Definition software. Start with the software to generate 3D models that contain all the product and manufacturing information. Recommended is to start generating 3D models of tools that contain a low accuracy, but complex geometry due to the functionality of the tool. The low accuracy is required due to limitations in the production of the Production department. The production of the Production department is not able to scan 3D at a high accuracy rate. The corresponding tools to start generating 3D models with the Model-Based Definition are the Top Guide Rail and the Stripper Plates.[30]

[30] The information is obtained through one online semi-structured interview with the CEO of B&W Software (9 years employed at B&W Software), one physical semi-structured interview with the Senior Tool Engineer (35 years employed at Besi Netherlands Packaging), and one physical semi-structured interview with the Mechanical Engineer (2 years employed at Besi Netherlands Packaging).

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Note, most information is retrieved from interviews conducted by Laura Eekelder.

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Appendix

Section 1.8 elaboration

Procedure for conducting interviews

Interviews are physically conducted. Exceptions are made for interviewees who are not in Besi Duiven. E.g., the Sr. engineer I-tech Development in China (Besi Leshan). Interviews take approximately 2 hours. To collect information, employees of the T&F Engineering-, Supply Chain-, Production- & Quality Control department(s) will be interviewed. For the T&F Engineering department, a Mechanical Engineer, Senior Tool Developer, and two Senior Tool Engineers will be interviewed. For the Supply Chain department, a Business Process Analyst, Purchaser, and a Work Preparator/Planner will be interviewed. Moreover, a Senior Production Engineer and a Sr. Engineer I-Tech Development will be interviewed for Production. To collect information on the Quality Control department(s) a Quality Engineer, Senior Production Engineer, and Sr. Engineer I-Tech Development will be interviewed. The interviewees work at Besi Netherlands Packaging for 30+ years, therefore the information is considered reliable. The Mechanical Engineer works approximately 2 years at Besi Netherlands Packaging. Therefore, new insights are included besides the 30+ years of interviewees. Before an interview, the questioned person will be informed about the upcoming interview. Demonstrations can be given by the interviewee when necessary for a better understanding. Most of the interviews will be semi-structured. In other words, a few questions will be prepared beforehand, but the remainder of the interview has the appearance of a conversation. Several interviews will be unstructured as well. It will be mentioned in the report when an unstructured- or semi-structured interview took place. In a situation of contradiction of the different interviews, more interviews will be conducted to figure out which persons are correct and which persons are incorrect.

Section 2.1 elaboration

The entire business flow of the tool of the Trim & Form Engineering department is depicted below.

Figure 7 Business Process Model Part 2

Figure 6 Business Process Model Part 1

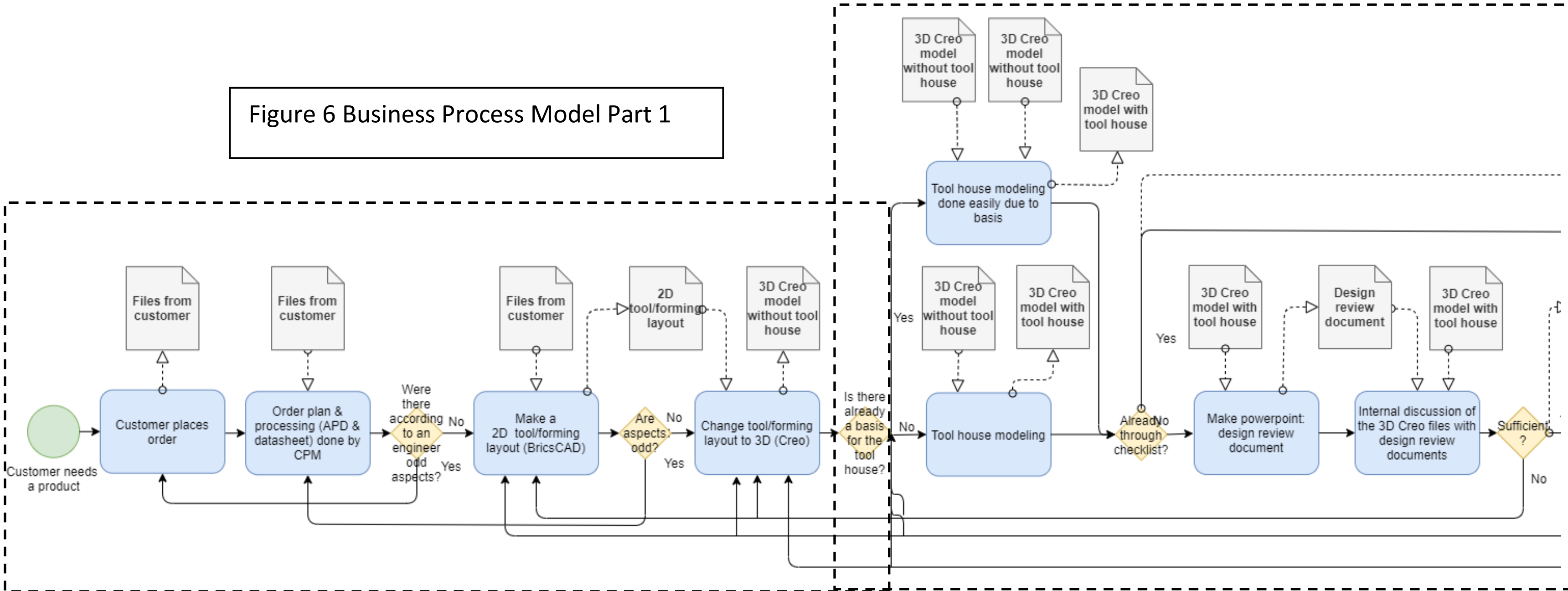
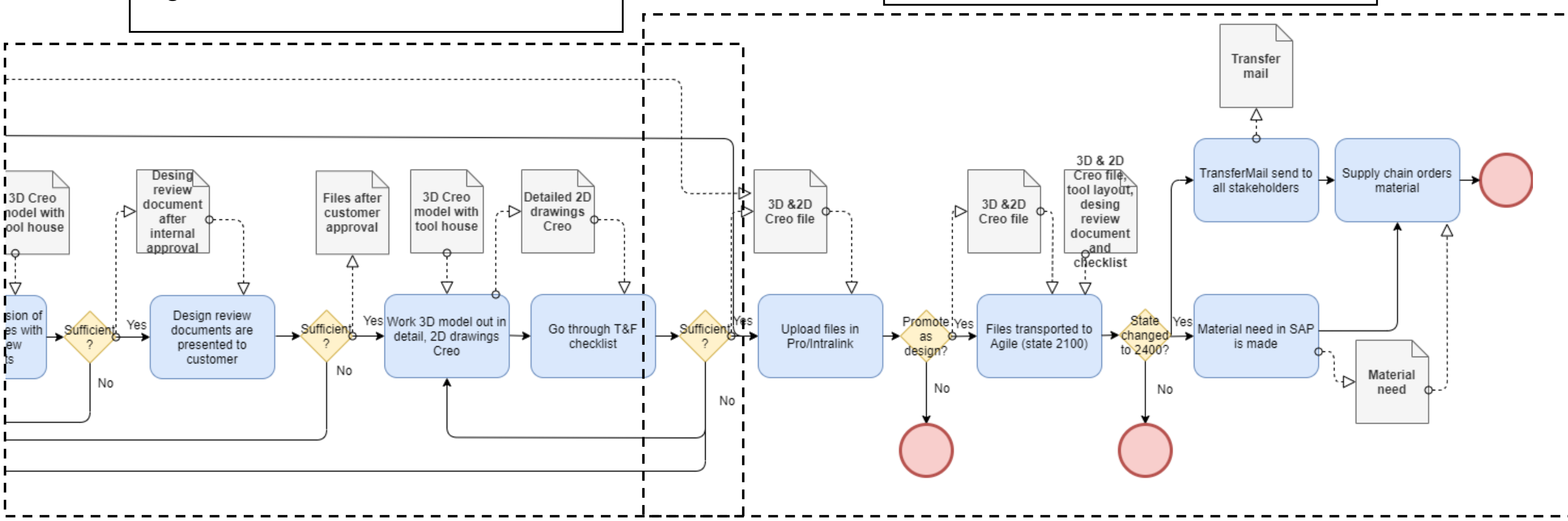


Figure 8 Business Process Model Part 3

Figure 9 Business Process Model Part 4



Section 2.2 elaboration

For the Separating tool, a small part of the detailed analysis is shown. A small part of the detailed drawing package analysis is shown in Table 23. (Refer Table 23)

Table 23 Example Detailed Drawing Package Analysis

part xxx	Material	Treatment	Tolerance			Angles tolerances			Geometric tolerances	Ordinate dimensions	Are there only symmetrical tolerances?	Hole table	Rougness	Remarks						
			[#/ values]			[Minutes]			[#/ values]	[Yes/No]	[Yes/No]	[Yes/No]	values							
2922216051	FTE-222	-	H7	H7	1	-	-	-	-	Yes	No	No	-	1	2	4	20	32		
			+0.05	-0.05	6															
			+0.25	0	3															
			+0.1	-0.1	17															
			+0.003	-0.003	9															
			+1	0	2															
			0	-0.02	2															
			0	-0.25	1															
			+0.2	-0.2	1															
			0	-0.05	4															
			+0.05	0	3															
			+0.5	0	4															
			+2	0	2															
			+0.05	+0.02	1															
			-0.003	-0.007	1															
2922216052	FTE-10	Hrc 57-59	+0.1	-0.1	29	-	-	-	-	Yes	No	No	-	1	2	4	20			
			+0.003	-0.003	2															
			+0.05	-0.05	6															
			+0.2	0	2															
			+0.05	0	1															
			+0.1	0	2															
			0	-0.1	1															
			+0.2	-0.2	2															

As indicated in Table 23 several remarks and tolerances occur. Table 24 indicates the different tolerances that occurred in the drawing packages and the problem (inefficiency) of the Trim & Form Engineering department. (Refer Table 24)

Table 24 Inefficient Tolerances

Tolerances	
Max	Min
+0.05	-0.05
+0.5	0
+0.01	-0.01
+0.1	-0.1
+0.05	-0.05
+0.01	0
+0.3	+0.1
h6	h6
0	-0.05
+0.20	0

Tolerances	
Max	Min
+0.5	-0.5
+0.2	0
+0.003	0
+0.005	-0.005
H7	H7
+0.1	0
0	-0.003
+0.05	0
0	-0.01
+0.02	0
0	-0.2
0	-0.02
+0.02	-0.02
-0.1	-0.3
+0.05	+0.02
0	-0.1
-0.2	-0.5
H6	H6
+1	0
+1	-1
-0.001	-0.004
0	-0.01
+2	0
0	-0.31
0	-0.005
+0.003	-0.003
+0.006	+0.002
+0.10	+0.05
+0.03	+0.01
+0.05	+0.01
+0.03	0
+0.1	0
-0.002	-0.006
0	-0.04
+0.2	-0.2
+0.005	0

Tolerances	
Max	Min
0	-0.004
+0.04	0
+0.04	-0.04
0	-0.03
0	-0.5
G7	G7
-0.02	-0.05
+0.020	+0.005
-0.003	-0.007
+0.03	+0.02
-0.01	-0.03
-0.1	-0.2
+0.05	-0.02
+0.25	0
0	-0.25
+0.3	+0.2
+0.3	-0.2
0.004	0.001

Furthermore, all the remarks found in the four drawing packages are depicted in Table 25. (Refer Table 25)

Table 25 Remarks on the Four Drawing Packages

Remarks	
1	Roughness general means -
2	Engravement information
3	Positioning geometric tolerance
4	Centrical (doesn't exist, means in Besi language that something is symmetrical)
5	Start hole indicated
6	Maximum material requirements (M)
7	Sharp corner S.C.
8	Specification of type plate
9	Perpendicular geometric tolerance
10	Flatness geometric tolerance

Remarks	
11	Glue dowelpin remark
12	Chamfer for wire EDM bur free production
13	Glue buffer remark 2900501002
14	Glue ID-tag remark
15	Undercuttig remark
16	Polish Ra
17	Remove sharp edge
18	TN35.05.19
19	TN35.11.08
20	TN08.02.02
21	Follow step or dxf file for missing dimensions
22	Sharp for cutting
23	Apply Ficoating
24	Radius point
25	Break sharp edge remark
26	Flat head remark
27	Square
28	Drill through remark
29	Glue bridge plate remark
30	Quart symbol
31	Around remark
32	Glue Eladur using loctite 480 2900075300
33	Regrind pushpin together with punchcarrier see 292216204
34	Glue polyuritane in Topplate
35	Ra (roughness) for the pockets
36	Undercutting according TN05.15.14
37	Regrind pushpin to correct dimension

Remark, for the entire analysis a separate Excel file is provided.

Section 4.2 elaboration

To determine the scores for the alternatives for the criteria Table 26 is generated. Table 26 depicts the value a_{ij} corresponding to the value of the alternative. Table 26 is used to determine the scores of the alternatives among each other. (Refer Table 26)

Table 26 Scale for the interpretation of the Pairwise Comparison Matrix

Interpretation of Pairwise Comparison Matrix				
Value a_{ij}	Interpretation	Investment costs [euros]	Operational costs [euros]	Engineering hours [hours]
1	Equal importance (i and j are equally important)	0	0	0
3	Moderate importance (i is slightly more important than j)	33333.333	5000	-0.677
5	Strong importance (i is strongly more important than j)	55555.556	8333.333	-1.128
7	Very strong importance (i is very strongly more important than j)	77777.778	11666.667	-1.579
9	Extreme importance (i is absolutely more important than j)	100000	15000	-2.03
2,4,5,6,8	Intermediate values			
	1/3, 1/5, etc. values for inverse comparison			

Table 26 resulted in Pairwise Comparison Matrixes per criterion presented in the upcoming pages. The scores of the alternatives (MBD) compared to the other alternatives (MBD) are determined with Table 26. In other words, Pairwise Comparison Matrixes are determined with Table 26.

Investment cost criterion

Table 27 Pairwise Comparison Matrix B for the Investment Cost Criterion

-	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7
MBD 1	1	2.754	1	1	1.377	1.377	4.131
MBD 2	0.363	1	0.363	0.363	0.726	0.726	1.377
MBD 3	1	2.754	1	1	1.377	1.377	4.131
MBD 4	1	2.754	1	1	1.377	1.377	4.131
MBD 5	0.726	1.377	0.726	0.726	1	1	2.754
MBD 6	0.726	1.377	0.726	0.726	1	1	2.754
MBD 7	0.242	0.726	0.242	0.242	0.363	0.363	1
Sum	5.058	12.742	5.058	5.058	7.220	7.220	20.278

Table 28 Normalized Pairwise Comparison Matrix for the Investment Cost Criterion

-	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	**b**
MBD 1	0.198	0.216	0.198	0.198	0.191	0.191	0.204	0.199
MBD 2	0.072	0.078	0.072	0.072	0.101	0.101	0.068	0.080
MBD 3	0.198	0.216	0.198	0.198	0.191	0.191	0.204	0.199
MBD 4	0.198	0.216	0.198	0.198	0.191	0.191	0.204	0.199
MBD 5	0.144	0.108	0.144	0.144	0.138	0.138	0.136	0.136
MBD 6	0.144	0.108	0.144	0.144	0.138	0.138	0.136	0.136
MBD 7	0.048	0.057	0.049	0.048	0.050	0.050	0.049	0.050

*Table 29 B****b***

-	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	The sum of the row	**b**	B***b**
MBD 1	0.199	0.221	0.199	0.199	0.187	0.187	0.207	1.400	0.199	7.030
MBD 2	0.072	0.080	0.072	0.072	0.099	0.099	0.069	0.564	0.080	7.011
MBD 3	0.199	0.221	0.199	0.199	0.187	0.187	0.207	1.400	0.199	7.030
MBD 4	0.199	0.221	0.199	0.199	0.187	0.187	0.207	1.400	0.199	7.030
MBD 5	0.145	0.111	0.145	0.145	0.136	0.136	0.138	0.955	0.136	7.021
MBD 6	0.145	0.111	0.145	0.145	0.136	0.136	0.138	0.955	0.136	7.021
MBD 7	0.048	0.058	0.048	0.048	0.049	0.049	0.050	0.352	0.050	7.028

Table 30 Consistency for the Investment Criterion

λmax	7.024
Consistency Index (C.I.)	0.004
Random Index (R.I.)	1.32
Consistency Ratio	0.003
If Consistency Ratio is <0.10, then the outcome is valid	Consistent

Operational costs criterion

Table 31 Pairwise Comparison Matrix C for the Operational Cost Criterion

_	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7
MBD 1	1	2.16	1	1	1.08	1.08	3.24
MBD 2	0.463	1	0.463	0.463	0.926	0.926	1.08
MBD 3	1	2.16	1	1	1.08	1.08	3.24
MBD 4	1	2.16	1	1	1.08	1.08	3.24
MBD 5	0.926	1.08	0.926	0.926	1	1	2.16
MBD 6	0.926	1.08	0.926	0.926	1	1	2.16
MBD 7	0.309	0.926	0.309	0.309	0.463	0.463	1
Sum	5.623	10.566	5.623	5.623	6.629	6.629	16.12

Table 32 Normalized Pairwise Comparison Matrix for the Operational Cost Criterion

_	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	**c**
MBD 1	0.178	0.204	0.178	0.178	0.163	0.163	0.201	0.181
MBD 2	0.082	0.095	0.082	0.082	0.140	0.140	0.067	0.098
MBD 3	0.178	0.204	0.178	0.178	0.163	0.163	0.201	0.181
MBD 4	0.178	0.204	0.178	0.178	0.163	0.163	0.201	0.181
MBD 5	0.165	0.102	0.165	0.165	0.151	0.151	0.134	0.147
MBD 6	0.165	0.102	0.165	0.165	0.151	0.151	0.134	0.147
MBD 7	0.055	0.088	0.055	0.055	0.070	0.070	0.062	0.065

*Table 33 C**c***

	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	The sum of the row	**c**	C***c**
MBD 1	0.181	0.212	0.181	0.181	0.159	0.159	0.210	1.283	0.181	7.100
MBD 2	0.084	0.098	0.084	0.084	0.136	0.136	0.070	0.692	0.098	7.043
MBD 3	0.181	0.212	0.181	0.181	0.159	0.159	0.210	1.283	0.181	7.100
MBD 4	0.181	0.212	0.181	0.181	0.159	0.159	0.210	1.283	0.181	7.100
MBD 5	0.167	0.106	0.167	0.167	0.147	0.147	0.140	1.043	0.147	7.075
MBD 6	0.167	0.106	0.167	0.167	0.147	0.147	0.140	1.043	0.147	7.075
MBD 7	0.056	0.091	0.056	0.056	0.068	0.068	0.065	0.460	0.065	7.087

Table 34 Consistency for the Operational Costs Criterion

λmax	7.083
Consistency Index (C.I.)	0.014
Random Index (R.I.)	1.32
Consistency Ratio	0.010
If Consistency Ratio is <0.10, then the outcome is valid	Consistent

Engineering hours criterion

Table 35 Pairwise Comparison Matrix D for the Engineering Hours Criterion

	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7
MBD 1	1	0.139	0.221	0.550	0.159	0.221	0.111
MBD 2	7.182	1	2.660	5.365	1.128	2.660	0.550
MBD 3	4.522	0.376	1	2.704	0.564	1	0.223
MBD 4	1.818	0.186	0.370	1	0.223	0.370	0.139
MBD 5	6.296	0.887	1.773	4.478	1	1.773	0.370
MBD 6	4.522	0.376	1	2.704	0.564	1	0.223
MBD 7	9	1.818	4.478	7.182	2.704	4.478	1
Sum	34.340	4.782	11.502	23.984	6.342	11.502	2.617

Table 36 Normalized Pairwise Comparison Matrix for the Engineering Hours Criterion

	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	**d**
MBD 1	0.029	0.029	0.019	0.023	0.025	0.019	0.042	0.027
MBD 2	0.209	0.209	0.231	0.224	0.178	0.231	0.210	0.213
MBD 3	0.132	0.079	0.087	0.113	0.089	0.087	0.085	0.096
MBD 4	0.053	0.039	0.032	0.042	0.035	0.032	0.053	0.041
MBD 5	0.183	0.185	0.154	0.187	0.158	0.154	0.141	0.166
MBD 6	0.132	0.079	0.087	0.113	0.089	0.087	0.085	0.096
MBD 7	0.262	0.380	0.389	0.299	0.426	0.389	0.382	0.361

*Table 37 D*d*

-	MBD 1	MBD 2	MBD 3	MBD 4	MBD 5	MBD 6	MBD 7	The sum of the row	**d**	D***d**
MBD 1	0.027	0.030	0.021	0.023	0.026	0.021	0.040	0.188	0.027	7.027
MBD 2	0.192	0.213	0.255	0.219	0.187	0.255	0.199	1.521	0.213	7.133
MBD 3	0.121	0.080	0.096	0.111	0.094	0.096	0.081	0.678	0.096	7.069
MBD 4	0.049	0.040	0.035	0.041	0.037	0.035	0.050	0.288	0.041	7.030
MBD 5	0.168	0.189	0.170	0.183	0.166	0.170	0.134	1.180	0.166	7.105
MBD 6	0.121	0.080	0.096	0.111	0.094	0.096	0.081	0.678	0.096	7.069
MBD 7	0.241	0.388	0.429	0.294	0.449	0.429	0.361	2.591	0.361	7.173

Table 38 Consistency for the Engineering Hours Criterion

λmax	7.086
Consistency Index (C.I.)	0.014
Random Index (R.I.)	1.32
Consistency Ratio	0.011
If Consistency Ratio is <0.10, then the outcome is valid	Consistent

The scores assigned to all the possible Model-Based Definitions to the corresponding criterion are summarized in Table 39.

Table 39 Possible Model-Based Definitions with Criteria Scores

Criteria scores / Possible Model-Based Definition scores	Investment costs	Operational costs	Engineering hours
MBD 1	0.199	0.181	0.027
MBD 2	0.080	0.098	0.213
MBD 3	0.199	0.181	0.096
MBD 4	0.199	0.181	0.041
MBD 5	0.136	0.147	0.166
MBD 6	0.136	0.147	0.096
MBD 7	0.050	0.065	0.361

In determining the scores and scales assumptions are made. Table 40 depicts the assumptions made *(Winston & Goldberg, 2004) (Manoj Mathew, 2018).*

Table 40 Assumptions for the AHP Input

Assumptions
4 Floating licenses are sufficient, reasoning the time difference between engineers in Europa and Asia
buys B&W Software software, operational costs are 17% of the purchase amount
Direct link between investment and operational costs
Purchase costs are only considered with respect to external costs. Costs of the engineers are not considered (engineering hours contain this already)
Smart Color is possible in Creo
A combination of Smart Annotate and Export would be a good combination
Europe and Asia engineers make the same amount of hours
Most time of the Besi employees will be put in the standardization
Sigmaxim is not considered, project for the project department of Besi
Smart update is not considered, does not add value for first MBD steps
Investment is based on Ansys investment
Adjustments 2D drawing
*Less detailing, but could crash due to the created measurements by Besi
Adjustments 3D model
*Less detailing, possible due to the visual view that the 3D model offers