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Towards standardised machine elements at a packaging provider

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Preface

This thesis was conducted at the Division of Packaging Logistics, Faculty of Engineering, Lund University in cooperation with Tetra Pak Packaging Solutions.

We would like to express grateful thanks to *Daniel Hellström* for his time taken to support us with reviewing of this thesis and serving us with knowledge in development methodology.

We appreciate the staff at LE 8 & 19 at Tetra Pak that introduced us to the department and provided us with information necessary to fulfil this thesis.

An extra thanks for the effort spent by our tutor at Tetra Pak, Henrik Karlsson, Technical Manager at C&A, for daily feedback on our progress and for great support.

At last, thank you Karin Viestam, Manager C&A, for the great conversations and for the opportunity to perform the master thesis at your department.

André Andersson and Johan Nilsson

Lund, May 5th 2010

Abstract

Purpose

The purpose of this Master Thesis is to propose a standardisation process, to act as a support when developing standardised machine elements within Tetra Pak. The standardisation process has the intention to investigate the potentials to reduce the variety of the machine elements by applying common elements in several machines.

Design/methodology/approach

The standardisation process is developed through altering between literature studies concerning product development and standardisation and real life observations. The studied literature is adapted to the specific purpose and the proposed process is applied to one machine element and is then refined to maximise the usability.

Findings

This thesis results in a proposed standardisation process, but also potential cost reductions that will be obtained if implementing standardised machine elements.

Research limitations/implications

The standardisation process is developed to fit general machine elements within distribution equipment at a packaging provider. It is applied and tested on one machine element, the belt brake. If it is applied to other areas and in other industries it may have to be refined.

Practical implications

If standardised machine elements are applied it will give rise to less required resources in areas such as: spare part handling, development and purchasing, it will also give rise to economies of scale.

Originality/value

The value of this thesis is a standardisation process which aims to reduce the variety of applied machine elements within the distribution equipment.

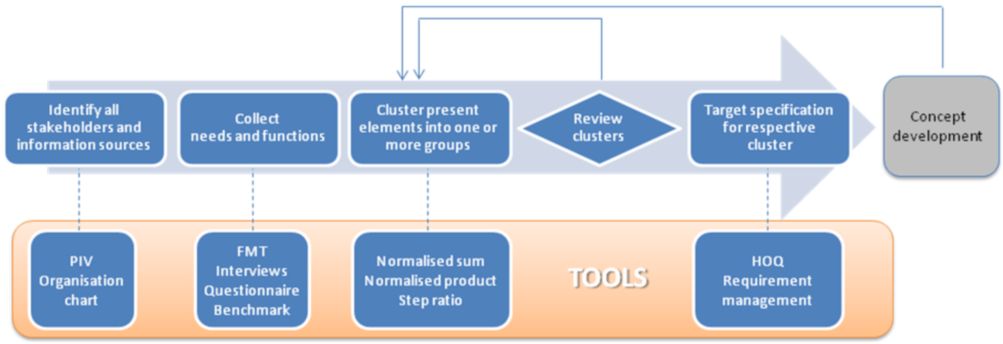
Sammanfattning

Tetra Pak är ett världsledande företag inom förpackningsteknik som bland annat utvecklar och tillhandahåller maskiner för distribution av kartongförpackningar. Idag utvecklas många maskiner individuellt vilket skapar stora mängder artiklar som både ska utvecklas, tillverkas och administreras. Tetra Pak's kunder har påpekat att maskiner känns onödigt olika varandra och att ledtiden för utveckling är onödigt lång. De beskrivna problemen kan elimineras eller minskas om maskinerna byggs upp av standardiserade maskinelement. Syftet med detta examensarbete är följande:

1. Föreslå en process för att reducera antalet unika konstruktioner för ett maskinelement.
2. Tillämpa processen på ett maskinelement för att försäkra den operationella förmågan hos den föreslagna processen.
3. Utvärdera den potentiella ekonomiska besparingen av standardiseringen.

Arbetsmetoden för att utveckla processen har varit abduktiv, det vill säga att punkt ett och två i syftet inte har utförts i en bestämd inbördes kronologisk ordning, utan snarare så att utveckling och tillämpning skett om vartannat. Befintlig litteratur inom området ligger till grund för processens utformning.

För att utforma processen på ett så användarvänligt sätt som möjligt för Tetra Pak studerades de nuvarande processerna för produktutveckling. Hänsyn togs till de anställdas åsikter om processer och dess användbarhet. En vanlig åsikt är att processerna beskriver vad som ska göras, men inte hur. Därför har verktyg för hur aktiviteterna i processen ska utföras föreslagits och de finns med i processbilden i Figur 1.



Figur 1. Föreslagen process, för större bild se Appendix J –Proposed process

Det som startar processen är önskemålet om att använda standardiserade maskinelement, vilket maskinelement som ska standardiseras ska vara fastställt. Målet med processen är att skapa ett underlag som beskriver vilka maskinelement som kan ersättas av ett gemensamt, samt en specifikation som beskriver vad detta ersättande maskinelement måste prestera för att nå framgång som ersättare.

Processen består av fyra aktiviteter samt ett beslutsfattande. Aktiviteterna beskrivs nedan i punktform:

- Första aktiviteten syftar till att kartlägga vilka intressenter som maskinelementet påverkar. Detta innebär framför allt att hitta vilka maskiner som innefattar maskinelementet ifråga och samla dessa tillsammans med lämpliga kontaktpersoner.

- Aktivitet två går ut på att samla in de behov och krav som maskinerna i vilka maskinelementen är placerade ställer på respektive maskinelement och att identifiera vilka funktioner som måste tillgodoses av maskinelementet ifråga.

- I tredje aktiviteten jämförs de identifierade maskinelementen med varandra och grupper av maskinelement med potential att ersättas av ett gemensamt maskinelement skapas. Tillvägagångssättet för denna uppdelning är metodisk och med fördel baserad på numeriska metoder. Detta för att kunna bibehålla objektivitet vid indelningen. Erfarenhet och personliga åsikter tas till vara först efter en metodisk uppdelning har genomförts.

- Fjärde och sista aktiviteten syftar till att skapa målsättande specifikationer för respektive grupp. Specifikationen är ämnad att användas i konceptutvecklingen och visualiserar på vilket sätt krav är kopplade till de behov som måste uppfyllas. Specifikationen utgör resultatet av den föreslagna processen.

För att försäkra sig om att den föreslagna processen fungerar i praktiken har processen tillämpats på ett maskinelement, den s.k. bandbromsen. 16 olika bandbromsar identifierades i tolv olika maskiner. För att få in behov och krav utifrån olika synvinklar valdes tre intressenter för respektive maskin: en konstruktör, en automationsingenjör och en teknisk chef. Kraven som samlades in bekräftades före användning genom att sända ut ett frågeformulär till intressenterna där möjligheten fanns att ändra och lägga till ytterligare krav. De funktioner som bandbromsen bestod av identifierades även med hjälp av ett functions means tree för att användas som en referens under arbetets gång. De behov och krav som samlats in för de olika bandbromsarna jämfördes sedan mot varandra för att kunna grupperas efter prestanda. Tre variabler valdes ut som uppfyller den fundamentala prestanda som krävs för att en bandbroms skall fungera: Förpackningsvolym, frekvens (rörelsemönster) och genomloppshastighet. Grupperingen utfördes objektivt på ett naturligt sätt där likheten i prestanda avgjorde hur många grupper som skulle skapas. Resultatet blev fyra grupper som kombinerade de 16 bandbromsarna. För varje grupp skapades en målsättande specifikation som beskriver den prestanda som minst måste erhållas av det ersättande maskinelementet.

Standardiserade maskinelement ger upphov till minskade kostnader i form av tillverkningskostnader (skalfördelar) och livstidskostnaden för en artikel. Med artikel avses en komponent inom en bandbroms t.ex. skruv, plåt och motor etc. Enligt en etablerad beräkningsmetod på Tetra Pak finns det en medellivstidskostnad beräknad för en artikel. Kostnaden innefattar administrativa kostnader i form av utveckling, inköp, reservdelshantering mm. Medellivstidskostnaden ligger till grund för de beräkningar som genomförts.

Varje reducerad bandbroms motsvarar i medeltal 112 reducerade artiklar vilket ger upphov till en kostnadsbesparing på ca 1 miljon kronor årligen. Ett annat sätt att reducera antalet artiklar är att öka andelen gemensamma artiklar mellan de standardiserade bandbromsarna.

När den skapade specifikationen skall användas vid konceptutveckling rekommenderas det att de standardiserade maskinelementen utvecklas parallellt i ett team bestående av intressenter från de olika bandbromsarna.

Table of Contents

1 Introduction

In the first chapter the reader will get an introduction to the background of this thesis and a definition of the problem to be solved. The purpose of this thesis is defined and also the focus and delimitations. Finally the disposition and the target group of the report are described.

1.1 Background

In today's increasingly competitive market, many companies need to satisfy a wide range of customer needs while keeping manufacturing costs as low as possible. They are faced with the challenge of providing as much variety as needed for the market with as little variety as possible between the products. Instead of designing new products one at a time, which results in poor commonality and standardisation and increases costs, many companies are now designing families of products based on common "elements" embodied in a product platform, enabling cost-effective development of a sufficient variety of products to meet customers' diverse requirements. Tetra Pak is a world leading packaging provider with potential to make profit from the advantages of commonality and standardisation.

1.2 Problem definition

Tetra Pak has several similar elements in its packaging machines, e.g. belt brakes that are all locally developed at five departments. These kind of similar machine elements are individually designed to fit into one single machine. Since the departments are responsible for a number of machines each there are approximately twenty machines that may include similar elements. This kind of similar elements may be developed and maintained as common elements, thus avoiding "inventing the wheel" over and over. To apply the use of common elements creates the potential to reduce the number of elements. In turn, this will reduce the use of administrative resources for development, engineering, purchasing, spare part handling, service etc.

Tetra Pak's internal customer surveys show that the time it takes for a product to reach the market is considered unnecessary long. One customer feedback reads *"...a lot of equipment seems to be "hand made"; no machine* *is similar to the next".* These feedbacks indicate the need for improvement of the development process. If standardised common elements are developed instead of many similar elements, the resources can be focused, which results in an improved development process that in turn enables higher quality products and shortened time to market.

Thus, there is a great potential in improvements if standardised machine elements are applied. However, there are several challenges to accomplish standardised machine elements. One challenge is to decide which existing machine elements that may be replaced by a common machine element. Another challenge is to identify what requirements the machines will set for the machine elements and to merge these into a single specification.

1.3 Purpose

The purpose of the master thesis is threefold:

- Propose a process for reducing the number of unique designs for a machine element.
- Apply the proposed process on one machine element i.e. Belt Brake, to assure the operational ability of the process.
- Investigate the potential cost savings in standardising machine elements.

1.4 Focus and delimitations

The proposed process needs to be adapted to Tetra Pak's existing tools to reduce the learning period and maximise the usability of this thesis. The language and the terms that are used within Tetra Pak will also be retained.

Tetra Pak has several machines installed at customer sites around the world. To assure that the requirements considered are up to date the focus will be on the machines that will be developed and maintained for further five years.

1.5 Disposition

- The first chapter aims to introduce the reader to the background and purpose of this thesis.
- The second chapter will give the reader knowledge in the methodologies used, but also explain how the authors have chosen to use them.
- Chapter number three describes the literature applied.
- The fourth chapter is a description of Tetra Pak and the processes used today, the description will help the reader to understand the origin situation of this thesis.
- Chapter number five aims to describe the designed process and how it is meant to be used.
- Chapter six is a description of how the process was applied to the machine element chosen, the belt brake.
- In chapter seven the results of a cost analysis regarding the benefits of using standardised machine elements is described.
- Finally, the eighth chapter reflects the conclusions that the authors have drawn from without the results.

1.6 Target group

This thesis is written especially for employees at Tetra Pak Packaging Solutions (TPPS). The process is of general character and may also be valuable for students at LTH and other universities that are interesting in standardisation of machine elements.

2 Methodology

In this chapter the reader will gain knowledge in the methods used for describing and solving problems. The authors approach will be described.

2.1 Type of Study[1]

The way of approaching a problem can be divided into different types of methodology depending on the knowledge already gathered about the problem. There are four types of studies: explorative, descriptive, explaining and normative.

Explorative studies are used in areas where there is narrow existing knowledge. The explorative studies are used to obtain an image of the problem, in what situations it may occur, and the parameters that are important to take into consideration.

Descriptive studies are used in areas where there is basic knowledge and the goal is to describe the problem, but not to investigate it.

Explaining studies aim to both describe and to explain a research area.

When an area already is described and explained and the aim is to present directions and propose improvements, the studies are called **normative.**

This thesis has been created as a *normative* study where the present situation was described at Tetra Pak and a well known problem within the area of standardisation was identified. To solve the problem, the proposal of a process that aims to support when standardising machine elements will be done. The standardisation of machine elements can result in direction of improvements in terms of utilisation of resources.

2.2 Approach of reasoning

In scientific research, altered reasoning can be applied to approach a problem. The approach can begin either by theoretical studies, practical

[1] Björklund M. and Paulsson U. (2003), *Seminariehandboken*, p.58

studies or a combination of the both. These different approaches are also named deductive, inductive and abductive.

The authors have applied the *abductive* approach during this thesis. This is a combination of the *inductive* and the *deductive* approaches which can be described as follows. The *inductive* approach is based on gathering of empirical data. This is made before studying theoretical information. The data is used to draw theoretical conclusions from an object. It is of high importance that the collected data is objective so that the conclusions drawn are impartial.[2]

When using the *deductive* approach of reasoning, hypothesis from existing theories are applied to understand the studied object. These hypotheses can be applied as long as logic and rules regarding theories are taken into consideration. It is thereby important that the object is well documented in theory. An ideal way of testing the hypotheses is by experimenting with systematic variation of the objects parameters.[3]

The authors have combined the use of both the inductive and deductive approaches during this thesis. In other words the abductive approach has been applied.[4] In Figure 1 below, the authors' approach of reasoning is described.

[2] Wallén G. (1996), Vetenskapsteori och forskningsmetodik, p.47-48

[3] Ibid

[4] Kovács G. and Spens K.M. (2005), Abductive reasoning in logistics research*, International Journal of Physical Distribution & Logistics Management* Vol.35 No.2 p.139

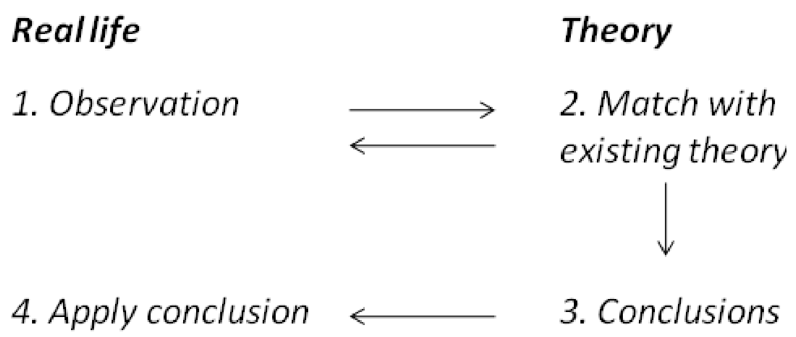


Figure 1 Schematic draft of reasoning used in this thesis.

1. In the beginning of this thesis a more inductive approach dominated the work. Tetra Pak's present global processes were observed to understand the significance and importance of them.

2. Existing literature in product development were studied to gain theoretical knowledge of the development process and compare them to Tetra Pak's global processes.

3. Then theoretical conclusions were drawn, conclusions regarding what further theories to apply. A more deductive approach has been used when discovered new theoretical tools that could be applied in this thesis. Hypotheses were drawn of the outcome on these tools to be familiar with the result.

4. The empirical testing was then applied to verify that the results were the expected. Depending on the result of the empirical testing, the hypotheses of the tools were either accepted and confirmed for use in this thesis or discarded. This has been a good approach when evaluating the different tools applicability.

2.3 Data collection[5]

There are a huge amount of different methods to apply when collecting data. The data collected can be divided into different types depending on the source, and method to collect the data. The data can belong to more than

[5] Holme I. M. and Solvang, B. K. (1997), Forskningsmetodik om kvalitativa och kvantitativa metoder, p.14

one type, for example can some data be collected from a primary source by a quantitative method.

2.3.1 Quantitative and qualitative data collection

A qualitative method's purpose is to create understanding and a general impression. The method should be designed to get a specialised and deep-going understanding.

Quantitative methods are used to obtain more ordered, formalised and controlled data. It is often possible to count or numerically measure the quantitative data. An important quantitative method in the analysis of information is statistic measurements.[6]

Both quantitative and qualitative data have been collected during this thesis. To create an overall understanding for the organisation, its processes and belt brakes several interviews were performed with stakeholders, which is a qualitative method. Quantitative data collection has also been performed by applying a questionnaire, especially on the data for the belt brakes, to collect the stakeholders' needs and technical requirements.

2.3.2 Primary and secondary data

The data collected can be divided into two types, primary data and secondary data. As the name indicates primary data is data from a primary source and vice versa for secondary data. Primary data is brought during the project, for example protocols from interviews performed for understanding Tetra Pak's development process. A secondary source is a construction of an occurrence, for example a book written and interpreted. The book itself should be based on primary sources. [7] Secondary sources have been applied in the form of books, articles and thesis.

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[6] Holme I. M. and Solvang, B. K. (1997), Forskningsmetodik om kvalitativa och kvantitativa metoder, p.14

[7] Bell J. (2009), Introduktion till Forskningsmetodik, p.125-126

2.3.3 Literature

Literature review is one of the most common applied practical methods to gain knowledge. In research, literature is every printed material: books, articles, reports etcetera. Not to forget is all the information to be found on the internet.

To find literature, different kinds of searches are useful. It is for example a great help when to find a book in a library and a necessity when to find literature on the internet. A search is often performed with the help of keywords. It is of important to choose the right keywords in a search and also in the written report. [8]A database that has been of great help during this thesis is the Electronic Library Information Navigator[9] (ELIN). Searches with keywords such as "s*tandardisation*", "*modularisation"* and "*quality function deployment"* have been made to gain results of scientific articles consisting of these keywords. If the results were comprehensive, the search was performed using logics such as: AND, OR and NOT to refine the results even more.

As can be seen in the list of references various types of literature have been used, such as books, scientific articles and dictionaries. The literature was gathered from both searches and recommendations from colleagues and tutors.

The quantitative method literature review were applied within Tetra Pak's information systems both to collect information about processes used within Tetra Pak and to gather technical information about machines and elements.

2.3.4 Interview

An interview is a simple way of collecting information from persons, but it is often time consuming to perform. It is therefore of great importance to choose the right respondent and to prepare the questions carefully with purpose to save time. Using recording equipment makes it easier to collect the information and to write it down at a later time. There might be a

[8] Ejvegård R. (2009), *Vetenskaplig metod,* p.47

[9] elin.lub.lu.se.ludwig.lub.lu.se, 100510

drawback of using recording equipment as some persons tend to be more restrictive as they are being recorded. One must take into consideration that the information collected during an interview always are affected by the interviewed persons personal opinions and must thereby be considered as subjective.[10]

To map the present situation and understand the present processes, a series of interviews were performed. The interviews have been both structured with questionnaires to follow and appointed meetings but also spontaneous where the interview turned into a discussion where certain subjects were discussed. To eliminate the risk of collecting subjective information through the interviews the authors made a plan of who the interviews would include. The interviewed group normally consisted of persons from different departments and in different positions. This also secures the reliability of the information. Interviews were also used to collect customer needs about the element which was used to apply the process, as already mentioned this machine element is a belt brake.

2.3.5 Questionnaire

The usage of questionnaires is a cheaper, simpler and less time consuming way of collecting information compared to interviews. Questionnaires reach large amounts of persons and the answers are written and thereby easier to process.[11]

To design a questionnaire is normally harder than expected. The way the questions are formulated is of great importance and may affect the answers. The formulation is therefore important to consider already in the opening phase. Another question that should be considered from the beginning is how to analyse the answers. If this is not done from the beginning, the whole

[10] Ejvegård R. (2009), *Vetenskaplig metod,* p.49-54
[11] Ibid

study might end up without any valuable results. The more structured a question is the easier it is to analyse. [12]

In this thesis questionnaires were used to; in a structured way collect and weight needs from different stakeholders, but also to confirm the needs already collected with interviews.

2.4 Judging quality

To ensure that all collected data can be used within this thesis the data has to be examined from different perspectives such as reliability, validity and objectivity. These measurements will set the quality of this thesis and if they are not taken into consideration the results of this thesis will not have any scientific value.[13]

2.4.1 Reliability

The reliability is a measure to ensure that the collected information is trustworthy to be employed. It is a measure to observe in which range a certain approach will give the same results at any given time, assuming that all the other aspects are the same. There might be many factors that influence the reliability within an approach. For example, when interviewing people, they have different thoughts that can affect the answers of the questions. If the answers differ from time to time, the interview will not be reliable.[14]

To ensure that the data collected during this thesis is reliable, the data had to be observed from without more than one source to be applied. Data were often gained through interviews, both formal and non-formal. By asking the same questions to more than one stakeholder the data were confirmed regarding reliability. When the data were collected, a questionnaire was sent to all stakeholders to confirm that the data collected was reliable. Tetra Pak's supporting systems was also used to confirm the values gained from the interviews.

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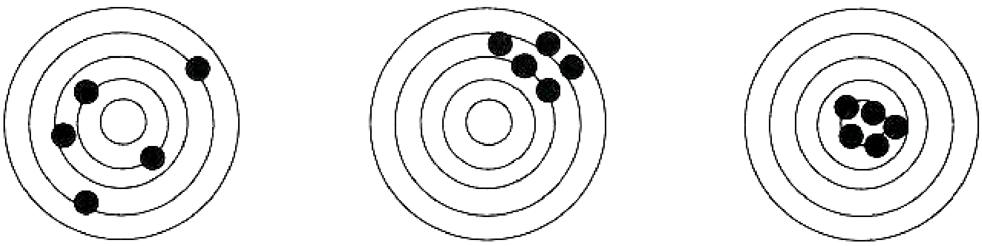
[12] Bell J. (2009), Introduktion till Forskningsmetodik, p.137
[13] Ejvegård R. (2009), Vetenskaplig metod, p.77
[14] Bell J. (2009), Introduktion till Forskningsmetodik, p.117

2.4.2 Validity

Validity is a measure that has various definitions. The easiest definition describes the validity as; to measure what intends to be measured. As long as an exact measure is defined and administered within a scientific work, it is less probability that the work will be invalid.[15]

If a question is unreliable, it is not possible that it will be valid either. But if the reliability is high, it is still not sure that the question is valid. For example, a question can have a similar answer depending on the time of the question but it can still be the wrong answers given.[16]

Figure 2 makes it easier for the reader to understand the validity and the reliability.



Low Reliability	High Reliability	High Reliability
Low Validity	Low Validity	High Validity

Figure 2. Illustration of reliability and validity with a dart board.[17]

To avoid applying invalid data the authors have had the ambition to be structured and planned during interviews and while creating questionnaires. The aim was to create questions that could only be interpreted in the

[15] Ejvegård R. (2009), Vetenskaplig metod, p.80-81
[16] Bell J. (2009), Introduktion till Forskningsmetodik p.118
[17] Picture of Reliability and validity (2001), Reflections on Process-based Supply Chain Modelling and Analysis

intended means. If there were a misunderstanding from a stakeholder, the authors contacted the stakeholder to discuss the interpretation.

2.4.3 Objectivity

The objectivity describes in what extent partiality affects the study. All scientists are responsible to aim against objectiveness in their work. The problem often lies within psychiatry and it can be hard to recognise and avoid partiality that prevents objective consideration in a situation. By clarify and motivate the choices made in a study the reader can create their own opinion, thus add more objectivity to the study.[18]

To ensure objectivity during this thesis the authors have been critical during the interviews. The authors have discussed the results from the interviews afterwards to detect any subjective opinions that might appear during the interview of a stakeholder. If found, complimentary questions were requested from the stakeholder and to other stakeholders that had similar knowledge to ensure that objective results were gained.

[18] Ejvegård R. (2009), Vetenskaplig metod, p.19

3 Literature review

The literature that has been applied during this thesis is concerning business process management, product development, specification establishment, commonality Indices, standardisation, modularisation and World Class Engineering. To be able to analyse and evaluate results in this thesis, the authors need to explain the theory that has been applied.

3.1 Business Process Management[19]

To understand the processes for product development and maintenance at Tetra Pak and to be able to describe the proposed process, literature of Business Process Management (BPM) were studied. BPM is a well documented approach of managing processes and will therefore be applied in this thesis.

Within the theories of BPM, processes are used. There are several definitions of a *process*, one commonly used is *“a repetitive used network of linked activities that uses information and resources to transform “incoming object” into “outgoing object”, from identify to satisfaction of the customer needs”*.

This definition describes the process with a distinct start and end point. It also describes that it is the customer needs that plays a central role within a process. The process itself is empty; it needs information together with resources to create value for the customer.

[19] Ljungberg A. and Larsson E. (2005), Processbaserad verksamhetsutveckling, p.44

The concept of a process as seen in Figure 3 is that the including activities and their relationship, the identified customer need and the resulting customer satisfaction is all related to *customer needs*. It is not possible to work with processes without taking care of the customer needs.

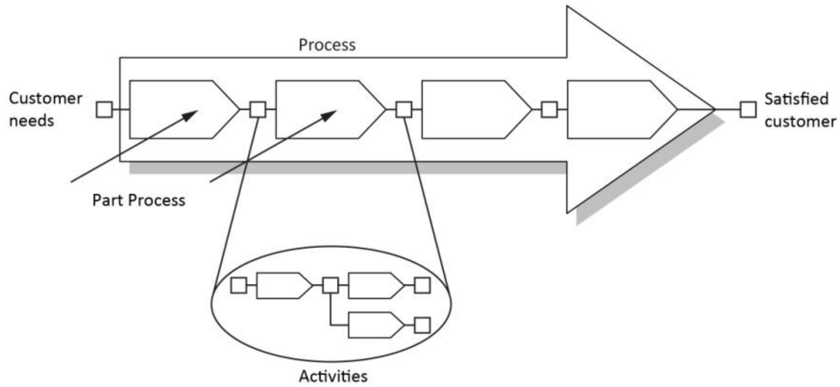


Figure 3. The concept of a process.[20]

The processes can be described different depending on what level of detail it illustrates; in this case there are three levels. A process is built up by *part processes*, which are built up by *activities*. The part processes is a sub level to the process and the activity is a sub level to part processes. The activity can be described as a series of acts that uses the available resources. Between the processes and activities there are incoming/outgoing objects.

Incoming objects is defined as a starting point for the process. Without the incoming object the process/part process/activity can not start. The outgoing object is the result of the transformation between the activities and the resources.

3.2 Product Design and Development

Product development is a wide subject that is described in various literatures. As the authors studied Tetra Paks development processes and compared to the literature of Product Design and Development there was found great

[20] Ljungberg A. and Larsson E. (2005), Processbaserad verksamhetsutveckling, p.44

similarities. The focus of this thesis is to maintain the language and terms applied at Tetra Pak which makes it natural to apply the literature of Product Design and Development.

The economic success of manufacturing firms depends on their ability to identify the needs of customers and to quickly create products to satisfy these needs. If the products also can be produced at low costs the product has good chances to be a success. To make such product is not solely a marketing problem, nor is it solely a design problem or a manufacturing problem. It is rather a product developing problem, dependent on all these functions. The product design and development theory provides a collection of methods intended to enhance the abilities of cross-functional teams to work together to develop products. [21]

3.2.1 Product specifications[22]

Development of a product, whether it is a new or existing product, is a time consuming task. To know what to focus on, it is important to start gather information about what needs that are important for the final product. This can be completed in a list of *product specifications*.

A product specification lists the most important requirements for developing a product. The definition of a *specification* consists of a metric and a value. This specification is entered into a list, for example as "*straws*, weight, < 0,5grams". The value can be either a strict value or a span of accepted values that uses the same units through the list. This is done to have a strict frame about what requirements that has to be fulfilled when starting to develop a product. It will tell the developers "*what*" to do, not "*how*" to complete the task. This is to ensure that creativity is applied when developing the product. The more thorough the information gathering is, a more complete list of product specifications will be constructed, with better opportunity of a final product that will have fewer issues.

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[21] Ulrich K. and Eppinger S. (2008), *Product Design and Development, p.2*
[22] Ibid

To gather the information that is needed, a detailed analysis of needs is important as it is a vital factor for achieving success in product development.[23] The needs can be expressed as "*language of the customer*". These needs will be expressed in general terms as the customer is not familiar with the developing process, for example "I want a fast car". These needs have to be translated and cascaded down into technical requirements that can be added to the list of product specifications, for example "*Acceleration*, torque, 500nm", as in Figure 4. It is essential that the developer translates *all* of the needs to cover the general customer terms.

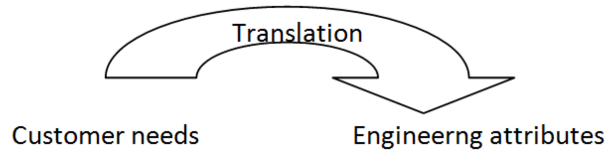

Figure 4. A customer's need shall be translated and cascaded down into technical requirements.[24]

There can also be other requirements that have to be fulfilled within the list of product specifications, such as legal or safety demands. These requirements are compulsory e.g. MUSTS and have to be taken into consideration when a product is developed, otherwise it can result in a devastating end of the product life.

In a development project it is important to establish the list of product specifications in the early hours of the project to be familiar with the potential of the final product. In the ideal world the developers will construct the product exactly as the requirements. This is only possible if the requirements are of a simple nature, such of developing soap with common ingredients. If the product is of a more technical complex nature it may require more than one list of product specifications during the development project. The first list of product specifications is created in the beginning of

[23] Khurana A. and Rosenthal S.R. (1998), Towards Holistic "Front Ends" in New Product Development, *Journal of Product Innovation Management* Vol.15 p.60-62
[24] Ulrich K. and Eppinger S. (2008), *Product Design and Development,* p.72-74

the project where the customer requirements are taken into consideration. This list is a called a *target specification* with aspirations and hopes that is created without thoughts of the technology constrains.

While the project moves on, it is common that the target specification have to be adjusted to meet constrains due to technology or financial attributes. This is presented in the list of product specifications called *final specifications*. To create the final specifications can be a hard trade-off to the customer needs as all interests are important. Figure 5 shows the development process where a target specification list is created after the customer needs is identified. The product concept will take place to evaluate the product, resulting in a final specification. The figure shows that a final specification is presented once but in certain organisations more loops within product concept are required to establish the final specification.

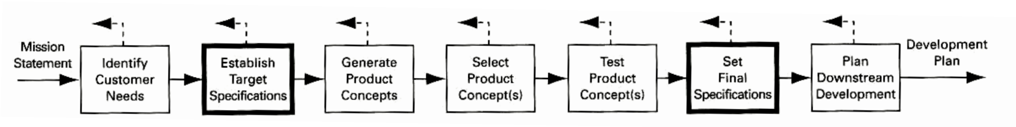

Figure 5. The concept development process. The target specifications are set early in the process, but setting the final specification must wait until after the product concept has been selected.

3.2.2 Concept screening[25]

The product design and development theory describes a method for concept screening developed by the late Stuart Pugh in the 1980s. It is often called Pugh concept selection and aims to narrow the number of concepts quickly, but also to improve the concepts. It is a six step method and can be used not only for product concept screening, but also for method concept screening. The result is a matrix that is shown in Table 1.

[25] Ulrich K. and Eppinger S. (2008), *Product Design and Development*, p.72-74

	Concepts						
Selection Criteria	**Concept 1 (Ref.)**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**	**Concept 7**
Criteria 1	0	+	+	-	+	-	+
Criteria 2	0	-	-	-	0	+	-
Criteria 3	0	-	-	-	0	+	-
Criteria 4	0	-	-	+	+	-	0
Criteria 5	0	-	-	-	0	+	-
Sum+	0	1	1	1	2	3	1
Sum-	0	4	4	4	0	2	3
Sum0	5	0	0	0	3	0	1
Net score	0	-3	-3	-3	2	1	-2
Rank	**3**	**5**	**5**	**5**	**1**	**2**	**4**

Table 1. Pugh concept selection matrix

The six steps read as follows:

1. **Prepare the selection matrix**
   The concepts to select from and the criteria from which the evaluation will be made are entered in the matrix. The concept which the user is most familiar to is chosen as reference as this will ease while comparing the concepts.

2. **Rate the concepts**
   A relative score of “better than” (+), “same as” (0) and “worse than” (-) is placed in the respective cell for every concept and criteria.

3. **Rank the concepts**
   The rating scores are summarised for every concept and the concepts are ranked, where the concept with the highest score is ranked as number one, the best and then following order.

4. **Combine and improve the concepts**
   After the ranking is done it is time to verify that the results make sense and then consider if there are ways to combine and improve certain concepts.

5. **Select one or more concepts**
   As the concepts are understood and its relative qualities are set, the best concept or combination of concepts are chosen. Based upon the

previous steps in the screening it is likely that the most promising concepts are found.

6. **Reflect on the results and the process**
   It is important that all participants in the development agree that the best concept is chosen. Otherwise perhaps one or more criteria are missing in the screening or perhaps a particular rating is in error. The fact that all members agree to the chosen concept decreases the likelihood of making a vital mistake.

3.3 Quality Function Deployment

The Quality Function Deployment literature was chosen to be applied as it involves high-detailed technical specifications that are similar to Tetra Paks World Class Engineering methodology, in that way it will be easier for the employees to get familiar with the specification.

American Supplier Institute (ASI) defines Quality Function Deployment (QFD) as:

"…A system for translating customer needs into appropriate company requirements at every stage, from research through production design and development, to manufacture, distribution, installation and marketing, sales and services [ASI, 1987]."

The QFD is normally used before starting activities within development, engineering and production of new products and services[26].

Within Quality Function Deployment there is a powerful tool that the authors found useful, it is entitled *House of Quality*. The tool is described below in the chapter 3.3.1 House of Quality and is a part of the QFD.

3.3.1 House of Quality[27]

The House of Quality (HoQ) is a matrix that describes the transition from a list of customer needs, also called "*WHATS*", through to a list where answers of

[26] Oakland J. S. (2004), Oakland on Quality Management
[27] Ibid

“HOW” the needs will be met. In other words, it is a tool to support transforming the customer needs into technical requirements. The expression “WHATS” will from now on be referred to as “customer needs” and the “technical requirements” will be referred to as “engineering attributes”.

The HoQ can be directly related to the *target specification* document as described in 3.2.1 Product specifications.

The customer needs are unclear in the way that they cannot easily be measured. Though the needs are very important for the development, the voice of the customer shall be kept as it is collected without changes.

To be able to fulfil the customers’ expectations, the needs have to be transformed into a technical point of view. Figure 6 below illustrates a House of Quality where the needs are located vertically in the left column and the translated engineering attributes are located in top in horizontally. The complex network of relationship between the customer needs and the engineering attributes can be identified and in that way be taken into consideration. The relationship is described by symbols that indicate a weak, medium or strong relationship. The symbols used are a *triangle* for weak relationship, a *circle* for medium relationship and *two concentric circles* for a strong relationship. If there are no relationships, the corresponding cells are left blank which means that the transformation of needs into engineering attributes is inapplicable.

The ability to transform plans into actions using QFD and by using repeated cross-checks on the analysed elements makes it a suitable tool for testing the compliance of the various aspects involved in a project.

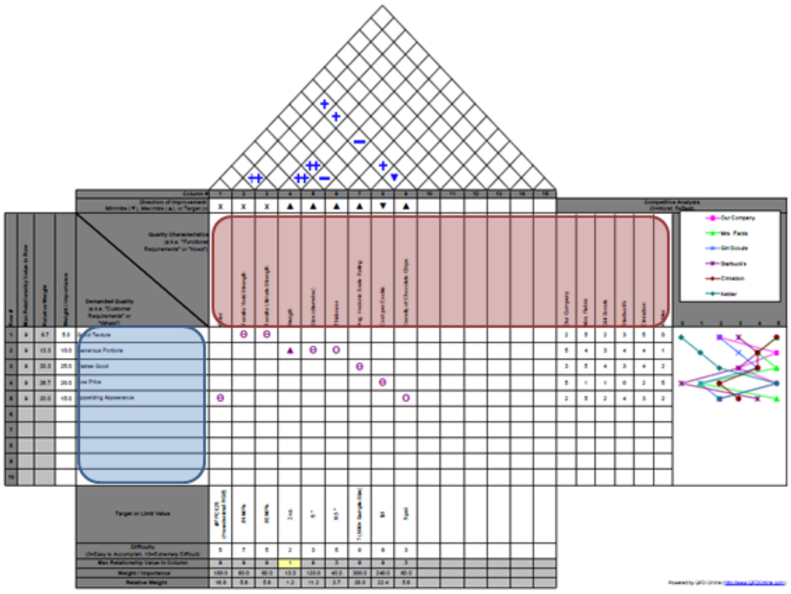

Figure 6. House of Quality. Visualises the relationship between the needs on the vertical axis and the engineering attributes on the horizontal axis. Correlation between the engineering attributes is presented on the “roof”.[28]

Parallel to the engineering attributes-axis in the bottom of the matrix there is an axis consisting of “*target/limit values*”. In these cells the values of the engineering attributes are defined as a measure. They are separated because at the time the engineering attributes are decided, the values are not yet known. The values serve both to confirm that a need is met and at the same time it sets targets for the technical solution that is to be developed. During the projects process they also works as guidelines to check that the progress is effectively maintained. The “*target/limit values*” should, as far as possible, be measureable values that can be taken into consideration in further analysis.

The roof, that has the shape of a triangle, is used to visualise the correlation between the engineering attributes by using a positive, negative or double positive marking. On the right, a comparison diagram is used to benchmark the competitors’ products.

[28] *www.qfdonline.com/templates*, 100517

3.4 Standardisation

The stakeholders are interested in standardisation of machine elements to be able to recognise and maintain only a few variants of each element, which will remove the feeling of "every machine seems to be handmade" that has been collected during customer feedback. As the purpose of this thesis includes standardisation of machine elements, literature concerning standardisation and modularisation has been studied to gain knowledge and to define the subjects within the development departments at Tetra Pak.

Major purposes of standardisation work are for example:[29]

- Assure exchangeability and compatibleness through standardisation of dimensions, measures and interfaces etcetera.
- Achieve limitations in variety through standardisation of dimensions, measures, and interfaces etcetera.
- Gain higher productivity, larger batch sizes, reduced stock level and get economies of scale.[30]
- Provide flexibility through modularisation.
- Normalise properties, functions, qualities and safety for products, processes, systems and services.

[29] *www.ne.se*, keyword: standardisering, 100504

[30] Agard B., Kusiak A. (2004), Standardization of Components, Products and Processes with Data Mining, p.2

Standardisation can be introduced on different levels as can be seen in Figure 7. When standardisation is mentioned in this thesis it is primarily on the machine element level, as the purpose aim to standardisation of machine elements.

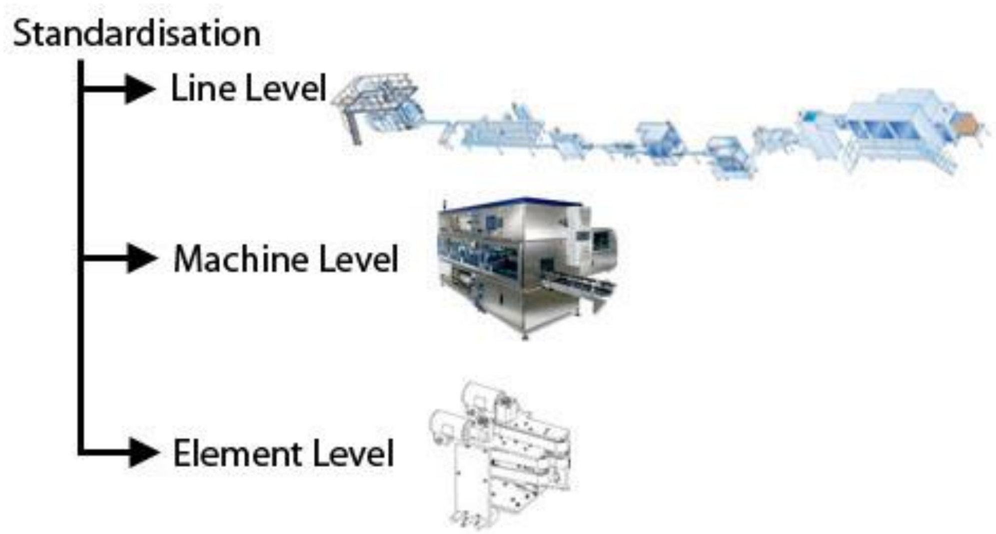

Figure 7. Standardisation made on different levels.

The proposed process refers to the situation in which several machine elements are replaced by a single element that can perform the functions of them all. This situation directly connects to the subject of commonality.

While standardising the machine elements, there are three possible situations.

1. Machine element standardisation within a machine:

   Several unique machine elements in a product are replaced by a common element.

2. Machine element standardisation among machines:

   Several unique machine elements in different products are replaced by a common element.

3. Machine element standardisation among machine generations:

Common machine elements are used in different machines or in upgraded machines across the time frame.

The literature related to standardisation of machine elements are more often related with situation number two. However there are several advantages to benefit from while considering standardisation of machine elements within the machines and among the machine generations. [31]

In this thesis the focus will be on the benefits drawn from machine element standardisation among machines, but as already mentioned there might still be potentials to benefit from standardisation of machine elements within the machines and among the machine generations.

3.4.1 Modularity

Modularity is a concept that has proved useful in a large number of fields that deal with complex systems. Also Tetra Pak has in some areas made profit from this way of handling product architecture. As this thesis does not aim to establish a modular architecture but rather a method to investigate the possibilities of creating common machine elements for several machines, the modularity concept is not central for this thesis. It should though be mentioned that creating common machine elements is one step towards a modular machine platform. By applying a modular machine platform the number of possible configurations achievable increases at the same time as the flexibility enhances[32].

A module might be defined as a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units. There are degrees of connection and thus there are gradations of modularity. A module might also be defined as sub-systems

[31] Perera H.S.C., Nagarur N. and Tabucanon M.T. (1999), Component part standardization, *International Journal of Production Economics* Vol.60-61 p.109-116

[32] Schilling M.A. (2000), Toward a general modular systems theory and its application to interfirm product modularity, *Academy of Management Review* Vol.25 No.2, p.312-335

within a machine that are bundled as a unit and which serve identifiable functions.[33]

As both these definitions match the regarded machine elements to standardise within this thesis, it is clear that standardising such elements is a step towards modular design. However, to accomplish a modular design, there are other aspects to consider. Such aspects will uppermost regard the design rules which include for instance interfaces between different modules but also the overall design of the machine platform. Such design rules are left out of this thesis.

3.5 Commonality indices

To assess the degree of commonality within a product family, several commonality indices have been developed during the years. They are based on different parameters such as costs, production volume, materials, and manufacturing processes, which is important information for ascertaining the cost saving benefits of commonality within a product family. Thereby, the use of commonality indices in element design can reduce the total cost of the product[34]. Indices may help designers manage the trade-offs between too much commonality (lack of product performance and product differentiation) and not enough commonality (higher manufacturing costs). Different commonality indices can be applied to single end items, product families, entire product lines, or to any level of product structure.[35]

The theory of commonality indices is mentioned as a possible tool to set potential goals in the proposed process and is applied to observe the percentage of commonality between the belt brakes.

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[33] Heikkilä J., Karjalainen T.M., Martio A. And Niininen P. (2002), *Products and modularity,* p.27

[34] Thonemann U.W. and Brandeau M. (2000), Optimal commonality in component design, *Operations Research* Vol.48 No.1 p.13-14

[35] Thevenot H. J., Fabrice A., Simpson T.W. and Shooter S.B (2007), An Index-based Method to Manage the Tradeoff between Diversity and Commonality during Product Family Design, *Concurrent Enginnering* Vol.15 No.2 p.127-139

3.6 World Class Engineering

World Class Engineering (WCE) is a methodology for product development, based on well known development theories that have been adapted to fit Tetra Pak's organisation. Examples of theories used are "quality function deployment" and "product design and development", both described briefly in chapter 3. At the Tetra Pak intranet the WCE is described as follows. "World Class Engineering combines skilled People working with best Practices within the right Process, to help deliver better performance and more innovation."[36] Parts of the WCE methodology have been used within this thesis. At the moment there are four main parts within WCE, Requirements Management Cascade, Architecture Design, Robust Design and Virtual Engineering. Requirements Management Cascade is the most relevant for this thesis as it contains valuable tools to map the functions of the belt brake. The tools used in this thesis are described in the following sections.

3.6.1 Requirement management cascade[37]

To understand and be able to use the methodology and its tools the authors attended a training course in this subject.

Requirements management cascade is a Tetra Pak procedure to define the system functions. It helps to connect the means to a certain function that will be delivered. It also helps to define performance measures and target values by which the stakeholders' needs will be satisfied. These performance measures are called engineering attributes within Tetra Pak.

According to internal documents requirements management is the procedure to:

- Define Functions at System, machine & module level.
- Define the Means by which the functions will be delivered.
- Define related Engineering attributes and their performance measures.

[36] Tetra Pak Orbis Intranet, *Development & Engineering*, 100414

[37] Tetra Pak Orbis Intranet, *WCE Requirement management cascade*, 100503

- Define Target values for the Engineering attributes, which have to be met in order to satisfy the Customer needs.

Within the Requirement management cascade course, the authors were educated to create a Functions Means Tree which is described below.

Functions Means Tree[38]

Function Means Tree shortened to FMT is a tool that helps to:

- Create a linkage between functionality and customer needs.
- Model system functions before committing to technical implementation
- Have a visual representation of a system that can be interpreted without deep technical knowledge
- Create a common understanding of the system.

The inputs to this tool are the customer needs. The function that the customer asks for is set on the top of the FMT and a technical solution is paired together with the function. As this main function is set it is split into primary level functions, as these have been paired together with respective technical solutions the cascading is repeated until the lowest element level is reached. Figure 8 shows an example of a FMT.

[38] Tetra Pak Internal, education material: *WCE Requirements managements cascade*, 100408

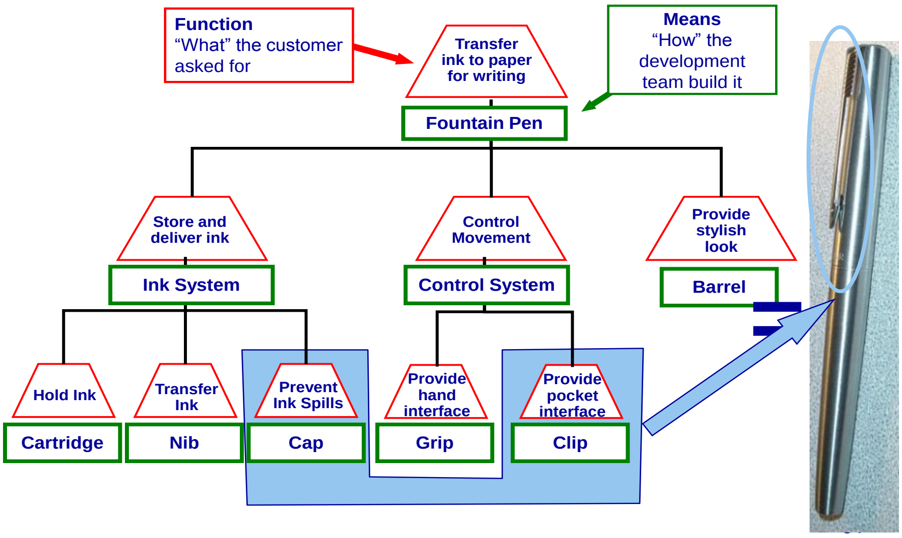

Figure 8. Example of a FMT, applied to a fountain pen.[39]

3.7 Cost analysis

A cost analysis has been conducted to support the proposed process and its advantages in cost savings. The authors have chosen to use the approach that Tetra Pak uses today regarding *life time cost analysis* for an article, also called the Bain cost model. An article is defined as a part of a machine element. A project for analyzing the life time cost for an article has been conducted internally at Tetra Pak and will act as a base in the analysis. The proposed process aims to reduce the number of machine elements that includes articles, by that the number of articles also will be reduced which makes the life time cost analysis applicable in this thesis.The Bain cost model originates from Bain & Company[40] which is a global business consulting firm that developed the model for analysis of an article's lifetime cost. The Bain cost refers to an average cost for the whole spectra of articles from screws up to large motors. At Tetra Pak, The Bain cost includes *developing*, *engineering*, *purchasing, spare part administration* and *service* during the lifetime of the article that is considered to be 20 years.

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[39] Tetra Pak Internal, education material: *WCE Requirements managements cascade*, 100518

[40] *www.bain.com*, 100504

4 Description of Tetra Pak's development processes

This chapter includes an overall description of Tetra Pak and its business areas. Some areas that are relevant for this thesis will be highlighted. Such as development processes, but also Tetra Pak's distribution equipment and the belt brake which the proposed standardisation process will be applied on.

4.1 Company presentation[41]

Tetra Pak is one of three autonomous industries included in Tetra Laval group. The other two are De Laval and Sidel. Tetra Pak is dedicated to the development, manufacture and sale of systems for processing, packaging and distribution of food products. Sidel produces machines for plastic bottles that are developed for liquid food. De Laval is further up in the product chain and their product portfolio is based on milk production.

Tetra Pak was founded 1951 in Lund by Ruben Rausing and Erik Wallenberg as an underlying company to Åkerlund Rausing. Tetra Pak delivered the first machine in 1952. It was a filling machine that produced tetrahedron shaped packages. The new machine was an innovation that changed the possibilities to distribute groceries all over the world. In the end of 1950s the Tetra Brik development started and 1963 it was introduced on the Swedish market. In 1981 the management team moved to Lausanne and Tetra Pak Rausing was founded. The company served as the international head office and was later renamed to Tetra Pak International SA. In 1991, Tetra Pak expanded into liquid food processing, plant engineering and cheese manufacturing equipment through the acquisition of Alfa-Laval. In 1993 Tetra-Laval was founded and in 2003 another acquisition was made. This time it was the French company Sidel that was bought up.

Today Tetra Pak group has over 21.000 employees and operates in close to 90 markets. The company is affected by its long history in many ways. The enormous variety of products is surely one outcome of this. The magnitude of

[41] *www.tetrapak.com/about_tetra*, 100530

products offers the customer great possible options, however, it has also give rise to the “unnecessary” wide range of machine elements, which wants to be reduced in this thesis.

4.1.1 Tetra Pak organisation

Tetra Pak is a major organisation that takes time to understand. Even though the authors worked in the organisation for five months it has not been an easy task to fully understand the organisation. The part of the organisation that the master thesis will cover is described together with a brief example of the production process. The need to understand the organisation is substantially to know where similar machine elements might be located, especially when they are to be found within different departments or even within different packaging platforms. To understand the origin of many requirements it is important to understand the whole range of products that form the line which starts with the processing equipment and ends with the distribution equipment. The machine elements that can be standardised are located within these ranges of products.

To understand the organisation it is of great help to study Figure 9 *while reading.*

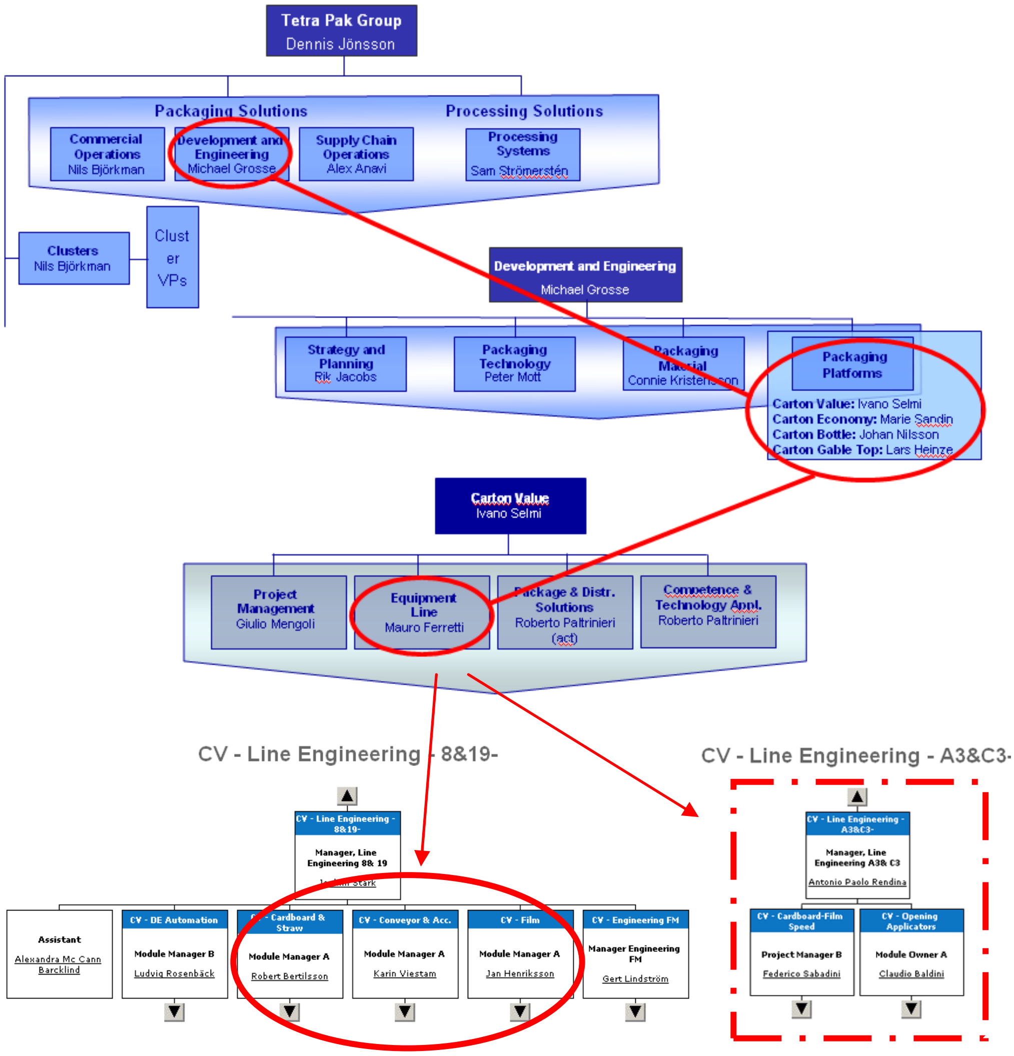

Figure 9. Draft of Tetra Pak organisation chart.[42] The marked area is where the authors belonged.

The Tetra Pak Group is divided into *Packaging Solutions* and *Processing Solutions*. *Processing Solutions* develops equipment for the customers to process the medium that shall be packaged. This involves pasteurising, homogenising and separation equipment (This part of Tetra Pak will not be

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[42] Tetra Pak Orbis Intranet, *Organisation chart*, 100504

considered during the master thesis). When the medium has been processed to its final condition it is transferred into a filling machine that fills and seals the packages with medium, the filling machines belong to packaging solutions.

Packaging Solutions contains Commercial Operations, *Development and Engineering* and Supply Chain Operations*.* All the filling machines are developed within *Development and Engineering* in the organisational chart and are divided into diverse *Packaging Platforms* depending on the customers' needs.

Tetra Pak is also producing packaging material for use together with their filling machines. The *Packaging Material* together with *Packaging Technology* is organised parallel to the *Packaging platforms* where packaging materials develop new package materials and packaging technology develops new concepts of packages*.* The filling machines together with the packaging material are sold to the customers that produce different kinds of fluid products, for example dairy products. This master thesis is mainly performed at the packaging platform named *Carton Value* but the aim is that it should applicable across all platforms.

As the fluid medium is processed and filled into packages it enters the final phase of the packaging line entitled *Downstream Equipment (DE),* which is the department that handles the machines regarding equipments for distribution. In DE department final modifications of the packages is completed before distribution of the packages to the consumer. In Figure 9 DE is represented by the departments round up beneath E*quipment Line.*

This thesis is performed within the DE department which is divided into the parallel departments of *Conveyor & Accumulation*, *Film Wrappers* and *Cardboard & Straw* which are located in Lund. The crosshatched square includes the departments of *Cardboard-Film Speed* and *Cap Applicators* which are located in Italy and also considered. To get a better understanding, these departments will be described separately beneath.

4.1.2 Tetra Pak Downstream Equipment[43]

The final modifications mentioned before consists of four value creating activities and a few supporting activities. The four value creating activities are Cardboard packing, film wrapping and straw- and cap-application. The supporting activities are conveying, accumulation, dividing, converging and turning the packages. Almost all of the machines, performing the mentioned activities are using some similar machine elements such as the belt brake.

Cardboard & Straw

The department named Cardboard & Straw is working primary with encapsulation of packages into trays and applying straws on single packages.

Encapsulation is performed by a type of machine named *Cardboard Packer* as seen in Figure 10 together with an encapsulated tray. A package arrives from a conveyor into the machine that collects the amount of packages that fits in a box. It will then put the packages on a cardboard sheet that will be folded until it is a totally closed tray.

Figure 10. Cardboard Packer and an encapsulated tray.

In this type of machines the belt brake is used to collect the arriving packages and feed them into the machine in a controlled way.

[43] Tetra Pak Orbis Intranet, *Products*, 100530

The straw is applied by a type of machines called *Straw Applicator*; this is shown in Figure 11 together with packages with an applied straw. The Straw Applicator is loaded with a coil of straws encapsulated in plastic. The incoming conveyor provides the machine with packages. When a package arrives, the machine applies two dots of glue on a straw and fixates the straw on the package in a continuous motion. In this type of machines there is a simple version of belt brake used to control the motion of the arriving packages.

Figure 11. Straw Applicator and packages with fixated straws.

Conveyor & Accumulation

Conveyor & Accumulation is the department which handles transfers of packages between the different machines. As seen in the left of Figure 11, a package conveyor is shown. It consists of a transfer belt with sides to prevent the packages from falling. When a package has been filled it will be transferred out on the conveyor belt and from there transported to the next machine. By using an optional control system called Conveyor Control System (CCS) the conveyor belt can also be coordinated to be used as a buffer.

The Helix Accumulator, seen in the middle of Figure 12, is a machine that can buffer the packages if any machines in the production line will break down or lose production capacity. It consists of a long conveyor belt that is twisted around an axis. It can allow, depending on the size of the accumulator, between 3-6 minutes[44] of service maintenance time until the whole production line has to be stopped. This is often enough to repair the most common failures.

A package divider is a machine that divides one lane into two lanes. This machine is normally used when a customer wants to use parallel lanes to double the capacity. It is built up by a brake that holds the incoming packages, together with an arm that divides the packages on the two outgoing lanes. If one of the outgoing lanes is empty, the arm will manoeuvre to that lane and send a signal to release the brake. A similar machine that converge the packages into one lane is also available. The converger can be seen on the right in Figure 12.

Figure 12. Package Conveyor, Helix Accumulator and a Converger.

The conveyor and the accumulator does not use any belt brake directly, however the conveyors often interfere indirectly with the belt brake. The converger and the divider on the other hand are built up with a belt brake that maybe is the most vital element.

[44] Tetra Pak Orbis Intranet, *Helix accumulation*, 100504

Film

The department of film is developing three kinds of machines. The *film wrapper* is one of them. This machine receives packages from a conveyor often through a belt brake. It collects and assembles the packages to a given pattern e.g. 2x3 packages and put a plastic film around it. The plastic film is used to protect and hold the packages together in a unit. The unit might then be heated in an oven to stick properly. A picture of a film wrapper and a unit tray is shown in 13. The other two machines handled by the film department are called *Multi Shrink* and *Tray Shrink*. These have a similar function as the film wrapper.

Figure 13. Film wrapper together with a plastic coated unit of four packages.

Cap Applicators

A cap applicator is a machine that applies caps on filled packages. A number of cap systems and cap applicators are available in the Tetra Pak product portfolio, though there are only two own developed cap applicators in use. The two are similar in construction and there is one belt brake in each machine, even the belt brakes are similar designed. The cap applicator is shown together with a capped package in Figure 14.

Figure 14. Cap Applicator together with a package with a cap system.

4.2 Global Processes

At Tetra Pak there is a well developed management system that describes how to work with different issues within Tetra Pak. The global process map shown in Figure 15 below shows the main processes and the main supporting processes that are used.[45] Within the department for downstream equipment the most used process is the process named Product Life-Cycle. As the name indicates the process is designed to use when an update on a product is needed. The Product Creation process is also relevant for this department as the department often is part of bigger projects driven by the product creation process, for example a new package development. This process is of course also used when developing a new machine inside the department.[46]

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[45] Tetra Pak Internal, *Management System*, 100319

[46] Interview with Linderoth R. and Elmhäll P., 100223

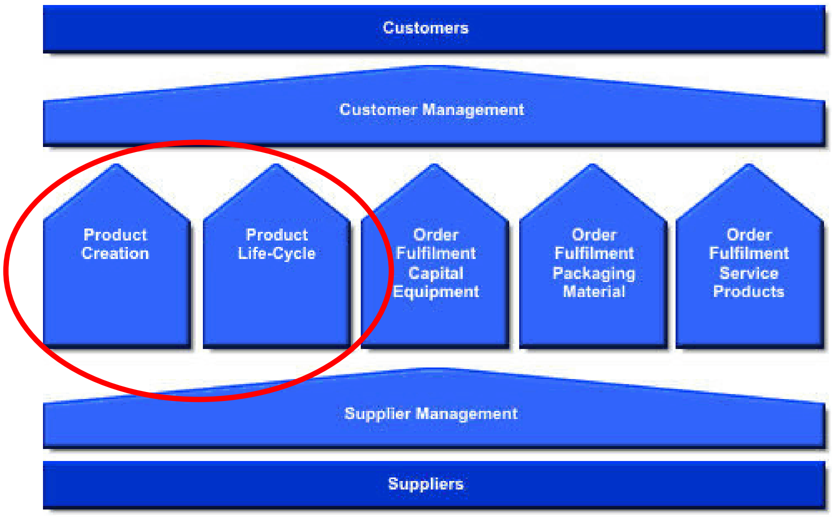

Figure 15. Global process map[47].

4.2.1 Product Creation

The process named product creation is first divided into two processes, technology development and product development. Technology development aims to develop new technology in a project. It can for example be a new technology for injection-mould the caps onto a package. The product development on the other hand is used to develop a new product. A process that tends to be very complex as it often includes a wide range of different departments. Of these two processes the product development process is the most relevant for this thesis, as new technologies not are developed at the department but at central organisation.

The part processes included in the product development are shown in Figure 16 below. When working with standardisation a lot of effort has to be put in the early stages of the process as marked in Figure 16.

[47] Tetra Pak Internal, *Management System*, 100319

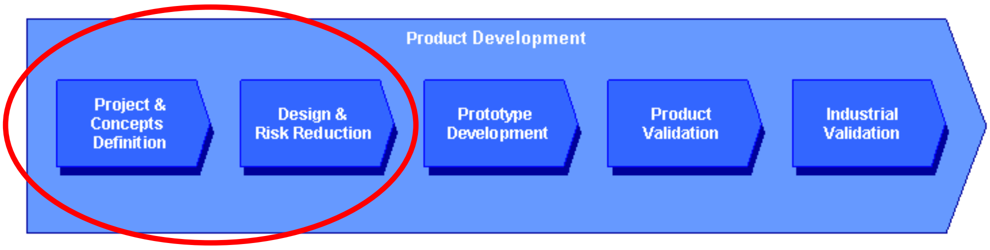

Figure 16. Part processes in the product development process.

The Product Creation process often shortened to PC has at the time of writing recently been updated. This means that many employees at Tetra Pak haven't been introduced to the process or at least haven't been working with it yet. The program to update PC is called PCR, which stands for Product Creation Redesign. This redesign was implemented with the following purpose:[48]

"The purpose of the PCR program is to review our existing product creation process, and in turn define and make changes to reduce time to market by 50% and double quality by 2010. This target is based on external benchmarking where Tetra Pak has been compared to other companies, as well as a close quality study based on customer surveys.

The PCR program is one part of the "Faster, Better, Cheaper" initiative across all Tetra Pak. It is also a continuation and integration of the World Class Engineering initiative."[49]

There are similar goals for this program as the problem definition of this thesis brings up. The goals to reduce time to market and increase the quality are both central in both.

The PC process is designed to handle all sizes of product development projects which include the largest. This result in a very large and complex process but the basics is similar to the product lifecycle process which is

[48] Tetra Pak Internal, *Management System*, 100412

[49] Tetra Pak Orbis Intranet, *Development & Engineering*, 100414

described next. Even though PCR is large and complex it is designed to be able to suite different sizes of projects.[50]

4.2.2 Product Life-Cycle

Life-Cycle is a process developed for redesign or removal of machines. The Product Life-Cycle process is normally activated by one of four occurrences. Accidents or incidents, product claims, product maintains or product removal.[51] The most common process in use in the downstream equipment department is the maintain process. The process is divided by six so called Toll Gates or TG. This means that the process is built up of five part processes, define, design and verify, validate and implement. The most common occurrence to start the process is requirements on machines to handle new packages, new legislative demands and when suppliers remove elements.[52]

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[50] Interview with Linderoth R. and Elmhäll P., 100223
[51] Tetra Pak Internal, *Management System*, 100504
[52] Interview with Linderoth R. and Elmhäll P., 100223

4.2.3 Tetra Pak innovation network

Tetra Pak innovation network (TPIN) is a web based process support tool used to learn and work in accordance with Tetra Pak Global Processes for Product Creation and Product Life Cycle. The tool has three dimensions or three purposes as shown in Figure 17.

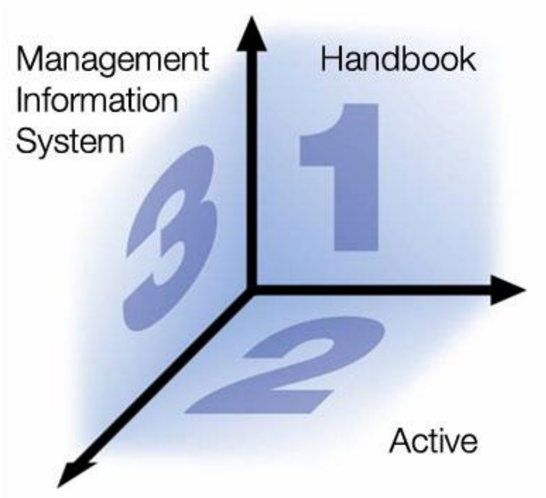


Figure 17. Illustration of the three dimensions within TPIN.[53]

The first is to serve as a handbook where TPIN visualises the related core-, primary- and sub-processes and activities. The handbook dimension is open for all Tetra Pak employees to look at when logged on as guests. The second dimension is the active dimension that is built to visualise, structure and support the work performed within selected primary processes and sub processes. The active dimension is also where you will find the tools to guide you in the process based work. Access to the active dimension is given to selected project members and management. The third dimension is used as a management information system, it contain status reporting, compliance reporting and financial measures. This is the source to many of the key performance indicators (KPI). Access to the management information system is highly restricted. [54]

[53] Tetra Pak Orbis Intranet, *Tetra Pak Innovation Network*, 100518

[54] Tetra Pak Orbis Intranet, *Tetra Pak Innovation Network*, 100315

4.2.4 Processes – Practical use

To investigate how the employees at Tetra Pak downstream equipment work with processes today an investigating series of interview took place. The interviews were designed as a short case study where the interviewed person had to choose an example of a project or activity to discuss in the following questions. The questions asked were the same to all of the interviewed persons as this will make it possible to compare the different case studies and analyse the results. The interview consisted of eight questions shown in Appendix A – Questionnaire Processes. The interviewed persons were chosen to represent different types of employees all affected by the existing processes but with different relations to it. The questions were asked to collect practical examples of how the existing processes are used. Another purpose with the questions was to collect personal opinions, but also to get an idea of how the processes are thought of by the users. This knowledge is vulnerable when developing new processes and is taken into consideration within this thesis. As the present processes where studied and understood it became clear that there are well developed processes to use for product development. All along the line it was found that in the processes for product development it is well defined what should be done but not as good defined how to do it. This is the background to why there for every activity also is one or a few tools presented in the process developed in this thesis.

4.3 Belt Brake

In this thesis a belt brake is defined as a machine that control items velocity using belts as the technical solution. Belt brakes are used in many applications within Tetra Pak. There are many different designs but the main functions are the same, to control the motion of a package or a unit of packages. The belt brake could be used either to retard or accelerate an item or simply to keep an exact velocity. A belt brake might also be used to provide a gap between packages which are useful in operation where the packages have to be counted.

4.3.1 Belt brake structure

The simplest structure of a belt brake is built up by two rolls and a belt, as shown in Figure 18. It could also be built up of just one roll and a rubber coating. To provide motion to the belts, some kind of motor is needed. To set the right speed and provide the right torque a gear box might be used. A body that will keep parts together is also required. As seen in Figure 18 a complete belt brake consist of many parts. Each of the belt brakes has their own specification with special requirements that requires various technical solutions depending on what machine they are located in.

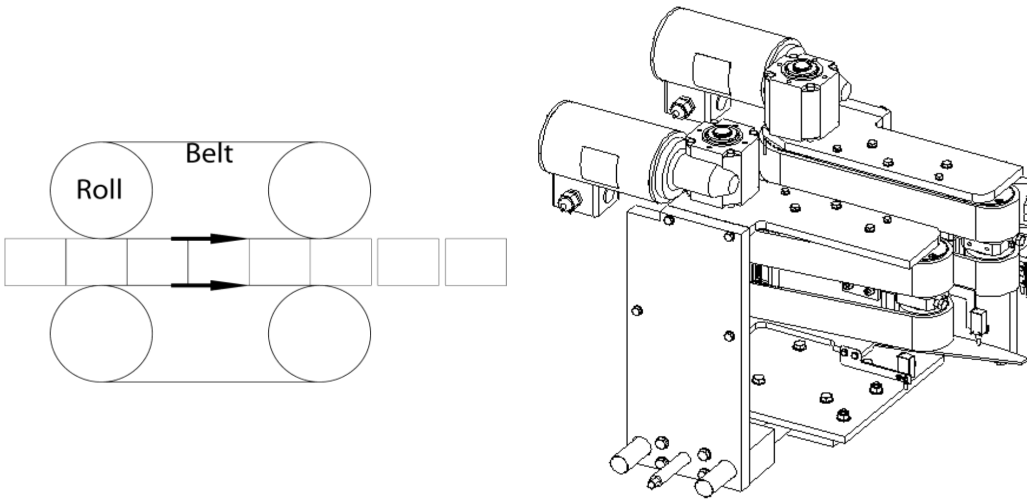


Figure 18. To the left: Draft of belt brake and packages aligned from above. To the right: A belt brake used today.[55]

[55] Tetra Pak Internal, *Product Information Viewer*, 100420

5 The standardisation process

This chapter presents the proposed standardisation process. Each activity in the process is described in a general way to be applicable on any machine element.

During the performed interviews it came clear that most participants found it useful to work with the present processes, some found it both useful and limiting but just few felt it was mostly limiting. The conclusion of the interviews was basically to keep the process simple or at least make it possible to keep it simple. This is a challenging task, especially when the process is built to handle big differences in project size. As the standardisation process is developed to handle a certain purpose this aspect is easier to deal with, but this aspect must still be considered.

To keep the process lucid it was designed as four activities to follow, shown in **Figure 19**. The first activity is to identify the stakeholders. The second is to collect the stakeholders' needs. The third is to cluster the present machine elements and the fourth and last activity is to establish one target specification for each cluster of machine elements. This specification will be the input to concept development, where the focus of this thesis ends. Between the third and the fourth activity a review of the clusters is made to decide if the clusters are applicable or shall be revised.

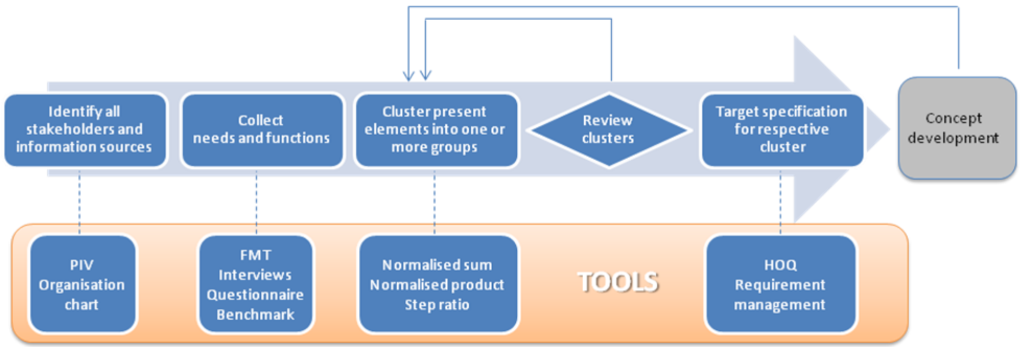


Figure 19. Proposed process. For a larger picture, see Appendix J –Proposed process

The tools shown below the process is applied in respective activity and the practical use of them is described for each activity in Chapter 6.

The BPM literature states that a process will be trigged of a customer need and result in a satisfied customer. As the background to this thesis indicates, the customers to Tetra Pak asks for machines that are more uniform than present machines, Tetra Pak asks for more cost-effective development and shorter development lead time. These “customer needs” are the triggers for the standardisation process. The result of the process is the target specification which enables further product development towards products which satisfies both Tetra Pak’s and their customer’s needs.

Each activity will be described in chapter 5.1 to 5.4, below.

5.1 Identify stakeholders and information sources

As the results of the process are a product of the inputs, the quality of the inputs is essential. To receive as correct inputs as possible it is also fundamental to find the right sources. To be able to standardise an element it is important to find out what the previously developed element performances are. It is also likely that the products’ stakeholders have comments and further desires for the products performance. When standardising an element it is as in all product development important to consider the voice of the stakeholders. However, it is not always obvious how to obtain the voice of the stakeholders. As the purpose of this thesis points on the importance to assure that the stakeholders’ needs are considered it is natural that the handling of the needs is a vital part all along the process. Within Tetra Pak downstream equipment a stakeholder is closely linked to the person responsible for the product (product owner) and its co-workers.

The stakeholders exist on several levels and can be divided into internal and external stakeholders. Internal stakeholders are found inside the company and external stakeholders are found outside the company. It is natural that it is easier to get in contact with the internal stakeholders and it is also natural that the internal stakeholders are better informed about specific elements in the machines. It is a long way between the end user (consumer) and the developers of a product which make it more difficult to find key stakeholders, but in the end it is the consumer that has to be satisfied with the developed product. This does not mean that it is necessary to go all the way to the end user to collect the needs. There is no necessity going further back in the stakeholder chain than to the point where the relevant information can be found. The internal and external stakeholders can be seen in Figure 20.

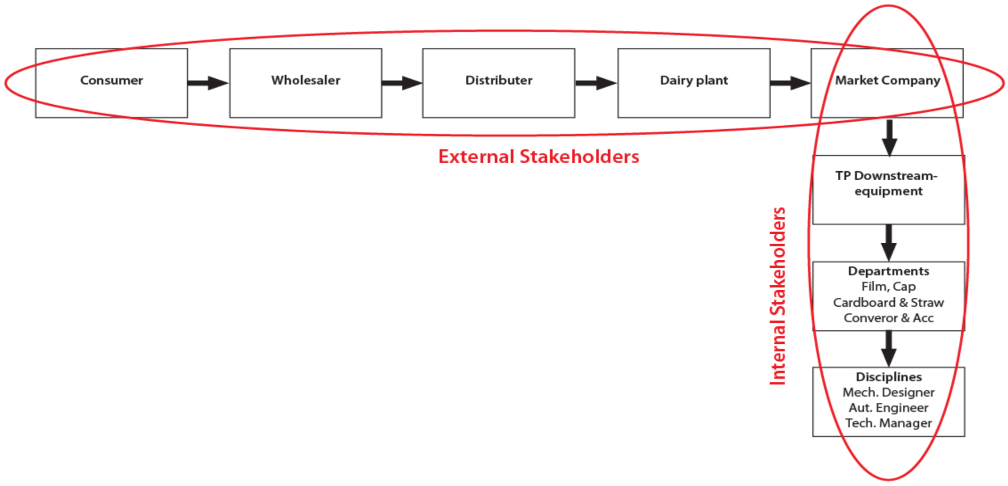


Figure 20. Customer chain visualising the stakeholders.

Who can be the stakeholders and the information sources for machine elements?

When studying the persons that are involved in the life cycle of a certain element in Tetra Pak downstream equipment, there are many stakeholders that are involved with different interests. The internal stakeholders are first described below categorised by department, the information sources are then described. The internal stakeholders are described together with their interests to avoid forgetting their opinions while developing standardised machine elements. It shall be mentioned that there can be additional valuable stakeholders from other parts of the organisation that has to be identified for a certain element.

Stakeholders by department:

- *Supply chain* –Supply chain is interested in handling fewer articles to provide less complexity, reduced stock and to maintain higher service level. They are also interested in providing economies of scale by ordering greater quantities of few articles.
- *Market companies* – The market companies have a direct contact to the customer and want to maintain a good relation. By standardising elements, it will reduce the complexity of the articles which will make it easier to track and trace the elements in both systems and in communication with the customer.
- Business Intelligence – One of business Intelligence's tasks is to provide information about competitors' by *benchmarking* their solutions. This can be very useful to compare against own solutions.
- Line engineering including:

  Technical Support –Technical support is working with support for the customers for at least twelve years after a machine has been sold to a customer. In that way they have interest in reducing the number of unique articles on the field. A standardisation of an element will result in fewer articles in the field and thereby reducing the amount of spare parts that technical support will handle. This will lead to less education and training of the service engineers and less complexity as every machine use a standard element. It will also be easier to give customer support as the service engineer will become more skilled on the standard elements and their behaviours.

  Mechanical Designers – The mechanical designers have a big effort to achieve a system of standard elements. To design an element that shall be used in machines with different appearances is not an easy task. A detailed product specification is then needed in order for the mechanical designer to create a good design of an element. As the common elements are in use there will also be advantages for the mechanical designer to put greater effort in robust design.

Automation Engineers – Machine element standardisation makes it easier for the automation engineers to create standard platforms in automation to control the machines as they need to handle fewer elements.

Product owners – Each element has a product owner that is responsible for a product and the elements within. It is thereby in their interest to maintain robust elements with a competitive manner that fulfils today's and tomorrow's requirements.

Technical managers – The technical managers have the technical knowledge of the elements and the functions within. They are greatly involved in the standardisation work since they are the managers of the technique.

Information sources – Tetra Pak has several systems to help supporting the business. The information sources often consist of huge amount of data that has to be extracted to be used in a practical way. Information sources that can be useful during standardisation are:

- *E*-liaison – A system that stores support information for common problems from the customers. Statistical data can be evaluated to reduce and avoid the amount of problems occurred regarding a certain element.

- Package Line Monitoring System *(PLMS)* – The system automatically logs all occurrences within an operating line which gives an overview of the elements that causes problems.

- Product Information Viewer *(PIV)* – PIV can be used to find all elements of a kind by searching a keyword that is related to the element. It is an internal system which contains all drawings of Tetra Pak's machines; it was used to locate belt brakes in machines that were not mentioned through interviews. PIV also contains all technical manuals related to the different downstream equipment.

- *Engineering experiences* – The engineering experiences is very powerful and a must to be applied during standardisation. As the stakeholders have experiences from different locations within Tetra Pak they can provide information relevant for the standardisation. Many engineers have also been to *customer visits* and therefore have important aspects to consider.

How can the stakeholders be located?

A good starting approach is to examine the organisational chart from top to bottom to find potential stakeholders. By contacting the manager of a certain department known to use the type of element that is to be standardised, further knowledge of the stakeholders can be gained. As the manager is responsible for the products within the department the manager is also a stakeholder that has needs on a high level, examples of those needs can be to reduce the overall costs or increase cooperation between the departments. Although, the manager is not often familiar with the technical part of the element but can often help to identify the stakeholders that are technically involved with the element. These stakeholders can often give good quality advices for use in the standardisation of the element.

The general opinion that were gained through interviews at Tetra Pak DE is that the organisation chart is not enough to find all the stakeholders as the knowledge can be spread over different departments. To overcome this, the Product Information Viewer (PIV) can be used to search and locate more elements in all available downstream equipment. If an element is found that has not been discovered before, it can be tracked to the department that is responsible for the element and in that way get in contact with new stakeholders.

All stakeholders that are identified and confirmed shall be documented in a structured way in a *stakeholder matrix* that can be seen in Appendix C – Stakeholder matrix. This is created to ensure that no stakeholders' interest will be lost during the work with standardisation of machine elements. It will also be a support for the project to know which stakeholder that is familiar with each element and what knowledge that is obtained. If a certain key person in the standardisation project is unavailable, other employees can use the stakeholder matrix to get in contact with the correct stakeholders.

5.2 Collect needs and functions

As the stakeholders and other information sources are identified, the needs from the respective must be collected to be able to cluster the elements into groups with similar requirements and finally create a target specification. As it is sometimes not clear even for the stakeholder what their needs are; this task can be much more complicated than the intuitive impression. The quality in form of validity and reliability of the needs collected is vital, since these needs will be translated into engineering attributes in the target specification. If the quality of the customer needs is low, there is a risk to develop a product that the customers never asked for.

Collecting needs from internal stakeholders can be done by simple and time efficient tools e.g. interviews, questionnaires and supporting systems like PIV. It is easy and time efficient since the internal network is well established and the internal stakeholders are in the same organisation as you. When it comes to external stakeholders tools like questionnaires and interviews are much more complicated and time consuming to use. It is possible to use these methods but it will be best performed by experts from the marketing department. There are other possibilities to gather information from the external customers. As described in chapter 5.1 there are a number of supporting systems that can be a helpful tool in this work, e.g. PLMS and e-liaison. One approach to assure reliability in the collected needs is to use more than one method to collect the same needs from the same source. While collecting needs this way the information will be confirmed. It is also possible, especially if the information source is a person, that there are needs more or less forgotten that will appear during such confirming research.

As the name of the activity indicates the functions of the machine element will be identified. This is done to compare the functions between the handled machine elements. The tool used within this activity is the Functions Means Tree (FMT), described in chapter 3.6.1. While setting the main function in the FMT and choosing the corresponding means, a limitation of the handled machine element is set. It is therefore important to choose the level of the function that corresponds to the machine element the user of this process would like to standardise.

5.2.1 Significant Attributes

Significant attributes were introduced into this activity as difficulties in the clustering activity appeared while considering all collected needs. To overcome the complexity with many detailed requirements in the clustering activity it was decided to reduce the level of detail of the requirements to a level where significant attributes could be used.

The *significant attributes* may not be the most important requirements. Rather, they are minimum requirements that any alternative must provide to be meaningful. For example are all legal requirements important since it is not an alternative not to fulfil these requirements, but they are still not considered as significant attributes as the functionality of the element is not depending on them. The significant attributes are requirements that have a reduced level of detail and shall picture the main functions of the machine element. To find the significant attribute the Function Means Tree is usable as this tool will help to find what the main functions of the machine element are.

The significant attributes can be applied either alone, or compared with each other to find an optimised solution for the most distinguished requirements to cluster on. The significant attributes can be divided into two groups that consist of the attributes that can be measured and the ones that cannot be measured. With measurable it is meant that a value can be set on a significant attribute. A measurable significant attribute can be easier to analyse in a methodical way as the values are able to be compared to each other. The reliability increases when working from without a methodical approach, since the values will be handled and treated equaly. This means that if different persons are utilising the methodical way to create clusters the same results will be received.

5.2.2 Legal requirements

The function of the belt brakes is comparable to each other. The belt brake can be both standalone or aligned inside a machine. If standalone, it requires a cover to comply with the European safety directives saying that a gap not more than 5 millimetres is allowed next to moving parts[56]. If the belt brake is aligned inside a machine, the cover of the machine will cover also the belt brake and a specific cover on top of the belt brake is not needed. All safety related requirements like the example above have to be considered through all the development process and is therefore preferably stated already in the target specification. Other examples of this kind of legal requirements are electronic standards and environmental requirements. These kinds of superincombent requirements are often the same for all machines and are already stated in predefined documents.

5.3 Cluster present elements into one or more groups

When the empirical study has been completed to collect the stakeholders' needs, a clustering activity will be performed to group all the elements. This activity is the first approach against standardising the elements and it is essential that it is performed properly. The more requirements collected, the better result can be achieved.

As the process refers to standardisation into less number of elements it is requested to create as big clusters as possible. The ambition is thereby to fit all of the significant attributes into one cluster, but several factors may impact the solutions to be more than one cluster. Factors that might impact the cluster size are design complexity and economical factors. It shall be known that projects that further develop existing elements will become more complex to perform since standardised elements will affect many applications. Thereby changes have to be adopted on all applications to maintain the standard element.

The tools for use when creating clusters can be more or less advanced depending on the amount of elements that is going to be standardised. A

[56] European machinery directive (2006/42/EC), 100505

common function that only includes a few variants of elements is not needed to be analysed with an advanced tool. The most important is to find the significant attributes that are distinguished for the function and evaluate the amount of clusters that shall be created.

If a common function includes a large number of elements (approx. 10<), it is of great importance that the elements are evaluated with a powerful tool such as Microsoft Excel or equivalent as the software manage to handle a large number of data in a structured way. The significant attributes can be expressed and analysed from without each elements view and also be benchmarked against each other in a methodical manner. A combination of the significant attributes in data values and a visualisation of the data with diagrams can be applied to get a good overview of the requirements which can be further used to evaluate the adequate clusters.

To create the clusters it is reasonable to execute a *group meeting* with relevant stakeholders. The results from the data analysis shall be used as a *support* together with the stakeholders' *intuitive* experience to find the elements that will be naturally clustered together, see Figure 21. It is important to discuss the criteria of *trade-offs* between costs, complexity, sold units, alternative costs and performance to obtain a high-quality cluster result that takes many variables into consideration. Risk management is also to be involved to exclude unsatisfied occurrences.

The stakeholders are obliged to be objective to find a solution that is the best intended for cost reduction and not for separate profit. When natural clusters have been created they shall be evaluated further to decide if to be merged or split up into another amount of clusters by comparing positive and negative aspects. A reminder to take into consideration is that less clusters has the potential to more likely reduce the costs. When the natural clusters have been analysed and the potential clusters have been chosen the next activity will be considered, to create a target specification that can be used for a concept study.

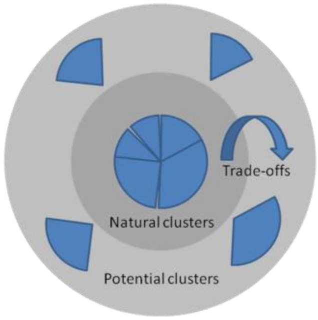


Figure 21. Cluster activity. Natural clusters are created at *Group meeting*, evaluation of them results in potential clusters.

5.4 Establishing Target Specification

As described in chapter 3.2 the target specifications are established after the customer needs are collected to act as a support while the concepts shall be generated. All the gathered needs must be translated into requirements to be useful in the creation of the specification. In the same activity the weighted needs will be used to create a priority of the created requirements.

An arbitrary setting of the specification may not be technically feasible. For example when designing a belt brake the development team cannot assume in advance that it will be possible to achieve a belt brake that can handle all packages and to every required speed alternative to a specified cost. Actually it is uncertain if there is a concept that will meet all the established requirements set at this time. For this reason, such preliminary specifications are named *target specification*. The specifications are the goals of the development team and they describe a product that is seen as the requested product from the customer. Later these specifications will be refined based on the limitations of the final concept.

Setting engineering attributes

The most useful engineering attributes are the ones that reflect how the product satisfies the customer needs as directly as possible. Therefore a good way to generate the engineering attributes is to consider each need in turn and to consider what precise measurable characteristic of the product will reflect the degree of satisfaction of the need. If the setting of the engineering attributes were ideal, there would only be one engineering attribute corresponding to every need. But in practise the needs corresponds to a number of engineering attributes since the needs often are general and thereby affects more than one specific engineering attribute.

For example, consider the need for short changeover time. This need naturally affect the changeover time for the element which is possible to achieve by a technical solution. But the technical solution developed to meet this need is likely to affect other engineering attributes such as the range of handled packages.

As a designer, many variables are used; some are dependent, such what material the machine element should be manufactured of. Other variables are independent such as the mass of an element. As an example the designers cannot control the mass directly as it arises from other independent variables, such as dimensions and material choices. The specification should tell the designer *what* the product shall do, not *how* it shall be done. For that reason the engineering attributes must be dependent, not independent.

The engineering attributes translated must be easy to measure. It is of no use to generate a metric that can only be measured in a laboratory environment at a very high cost. The engineering attributes are best as they are directly observable or analysable with little effort for the development team.

How can the engineering attributes be visualised?
Both *product design and development (PDD)(see chapter 3.2)* and *quality function deployment (QFD)(see chapter 3.2.2)* handles this activity and in the Tetra Pak methodology *WCE (see chapter 3.6.1)* this task is well developed. The approach of these different methodologies is similar to each other where the two first-named are more or less identical. The biggest differences between these two are that in *PDD* there are many different matrixes that visualise the results. In the *QFDs* approach named *house of quality* (HOQ) there are many results presented in the same document. In *WCE* there are different inputs compared to the two other methodologies brought up. Instead of finding which engineering attribute that corresponds to a product attribute the product attribute is paired together with a *functions means pair* (*FMP).* As a FMP includes a technical solution and the proposed process does

not aim to provide the technical solution, rather a specification to act as a support when developing a concept for the technical solution, this approach seems to be impropriate. On the other hand there are many similarities also between the *WCE* and the *HOQ*, it says in fact in the educational material for *WCE requirement management* that the approach used originates from the theory of *QFD.* As already mentioned the *HOQ* handles more information and are better suited to the purpose of this thesis and the authors have thereby decided to use the *HOQ* in their process for standardisation and specification generation.

As described in chapter 3.3 the inputs to the *HOQ* are the collected weighted needs, collected in the collect needs activity. As these needs are transformed into engineering attributes and target or limit values are set, the most important outputs from this approach are generated. Further outputs are the correlation diagram and the comparative diagram. The *HOQ* also offers the opportunity to implement a row for *direction of improvement* and another for *difficulty to accomplish.* These two rows seem to be of minor importance, but the fact that they are in the same document as the other specifications makes it useful with minimal extra effort.

There are engineering attributes that will not lend themselves to numerical values but rather to binary values like pass or fail. Other engineering attributes must meet targets to cover a certain range of packages. The target will then be a list of package models rather than a numeric value. The applied engineering attributes are collected and explained in Appendix I - Applied engineering attributes.

As described in chapter 3.2.1 there are needs that are considered as musts, even though they are measurable. As these are musts, there is no need to weight their importance since they are mandatory for the machines which the machine element will be a part of. An example is once again the range of handled package models that may be used. If a machine element is not capable of handling the packages that the machine is supposed to do, it is useless in that application.

The final product of the proposed process aims to deliver one *HOQ* for every cluster created in the earlier activity.

6 Applying the standardisation process

In this chapter it is described how the standardisation process was applied on one machine element, the belt brake. The results are presented and the outcomes are discussed. As the previous chapter, even this is divided in the four main activities of the process.

6.1 Identify stakeholders and information sources

The authors started to interview employees in a semi-structured way to get a feeling of which persons that could be potential stakeholders on different levels in the organisation. The identify part is about a great deal of information review by contacting potential stakeholders and requesting inputs that results in the building of a contact network. If the persons did not have an idea of the things that were asked for, they often could provide information about which persons that have worked with the belt brake and in what machine it was located in. The identify part continued by asking the recommended person. When a stakeholder was identified contact information were written down into the stakeholder matrix. By working forward in this way the most common stakeholders were identified.

It was also important to make an extra effort to find other potential stakeholders that have not been identified until now. Tetra Pak's internal network was used to study the current machine portfolio to ensure that there were no other belt brakes and stakeholders to take into consideration. The machines that had not been noticed before in the machine portfolio was examined in the PIV system to see if the drawings of the machines consisted of any yet unidentified belt brakes. Surprisingly there were a number of machines that included belt brakes that have been failed to be noticed during the interviews. Especially the machines that belong to the departments located in Italy were not noticed in the interviews as most of the interviewed persons were involved as stakeholders for the machines in Sweden.

To identify the stakeholders of the belt brakes located in the machines in Italy the authors used the *organisational chart* to track the department that developed the recently found machines with belt brakes within. The manager of the department was contacted to gain information about what persons at the department that were involved in the development of the belt brakes. In this way the authors used the advantage of the organisation chart to get in contact with the right stakeholders.

Finally, the authors identified 16 different belt brakes in the area of the downstream equipment, located in twelve different machines. All these belt brakes had stakeholders that were identified and can be seen in Appendix C – Stakeholder matrix. The authors have chosen to restrict the number of stakeholders to three per machine and to only focus on internal stakeholders, this is due to the limited time of this thesis. It is neither considered likely that the quality of the needs will increase significantly further back in the stakeholder chain. To obtain a wide observation of the stakeholders interests the three chosen stakeholders were from different positions: automation/test engineer, technical manager/technical expert and mechanical designer.

6.2 Collect needs and functions

The activity of collecting needs and functions might be divided into three steps.

1. Gain an overall knowledge about the needs for the machine element in focus.

2. Define the main functions and significant attributes. Used in the clustering activity.

3. Confirm and weight the needs in an objective way. Used when establishing target specifications.

Step 1

The first step in collecting needs from the stakeholders identified was a series of semi-structured interviews. This step aims gain an overall knowledge about the needs of the belt brake. A very important step for the authors since the previous knowledge in the area was restricted. But even for the most experienced in the area it is important to understand the stakeholder’s point of view.

Step 2

To identify the functions within a particular element a tool from the Tetra Pak *World Class Engineering* (WCE) methodology is used. The tool is named *Functions Means Tree* (FMT) and is described in 3.6.1 Requirement management cascade. By breaking down the element into its main functions and further down to sub-functions one can get a picture of which functions an element consist of and which are the vital functions in an element. As this is done it is easier to choose which functions that will have the bigger impact in the clustering activity and to choose the right significant attributes. To define the main functions of the belt brake the authors created a FMT of a general belt brake that can be seen in Appendix D – Function Means Tree. The FMT works as a reference of the functions that the technical solution shall satisfy. At present, more than one technical solution can be applied to fulfil the functions in FMT.

An example of this where while the PT 100 where compared to the general FMT. Two technical solutions were applied to fulfil all the functions in the general FMT. Instead, the belt brake could be implemented as the technical solution to fulfil the functions and thereby the present two technical solutions could be retired.

To find the significant attributes of a belt brake the authors tried to isolate what the main functions really was by asking themselves questions about the requirements collected from the stakeholders. *What requirements are needed for the element to work properly?* From the beginning, every requirement gives the impression of being the most important one. Certainly, all requirements are important, but all of the requirements are not essential to fulfil the fundamental operations of the belt brake. As knowledge was gained by interviewing stakeholders, the question was rewritten to: what are the most *significant attributes* that is needed for the element to work properly? The difference between the questions stated above is that there are a large number of requirements from the stakeholders that has to be taken into consideration, but to do it within a structured approach is difficult as it is getting truly complex to cluster many elements in the next activity.

Three significant attributes were chosen to describe the fundamental functions of the belt brake:

- *Package volume* [ml]
- *Frequency* [batch/time]
- *Minimum capacity* [packages/h]

The selected significant attributes is described below:

- **Package volume**

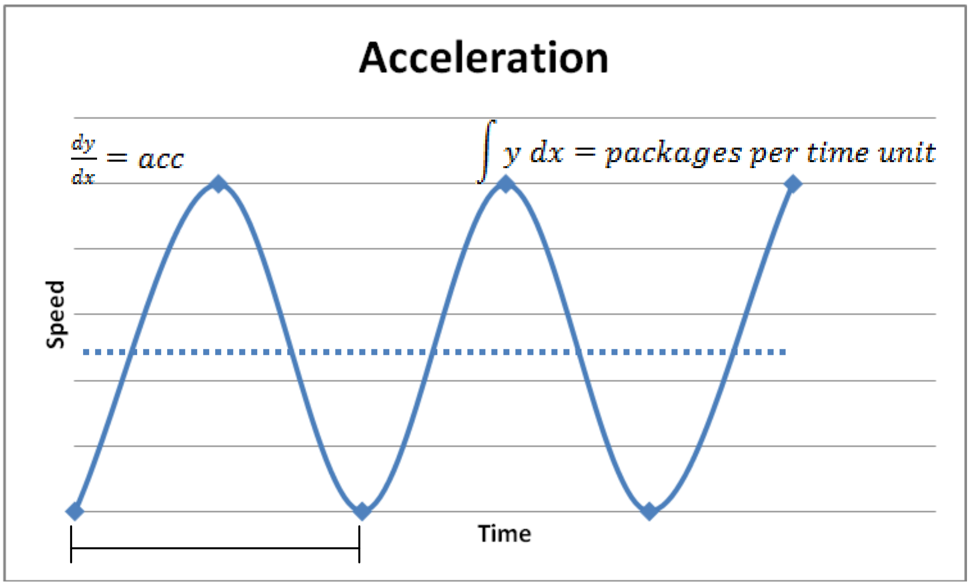
In order to discover the *package volume* as a significant attribute it was asked *what work that was going to be performed in the belt brake*? It was realised that packages should be transferred through the belt brake. Questions like "*what is the attribute of a package*?" were discussed and a number of attributes were pointed out. The *Shape, weight, volume,* and *friction* are important attributes for a package. After evaluating the package attributes it was decided to use the *volume* as the significant attribute because it is straightforward to measure, including many underlying requirements for the belt brake such as mass to transfer, acceleration, robustness etc. Since Tetra Pak mostly package liquid medium an approximation of the weight can be achieved by setting the density to one as for water. The other package attributes has to be taken into consideration at the concept creation.

- **Frequency**

What else is fundamental for the belt brake to work? It came up that the belt brakes *acceleration* of packages were important as it sets requirements on the equipment. The acceleration, as mentioned earlier, is hard to measure because there is no documented specification to be found. The only way is to measure the acceleration empirically which causes the problem to locate all the belt brakes at customer sites. *How can the acceleration be measured then*? By using pen and paper the authors came up with the idea to calculate a significant attribute entitled *frequency.* The frequency is a measureable value that can be given by identifying the amount of *packages per hour* that is transferred through the belt brake. Together with identifying *the minimum* *batch size* that is transferred through the belt brake each time it starts/stops the frequency can be calculated by:

$$Frequency = \frac{Packages\ per\ hour}{Minimum\ batch\ size} = \frac{Packages/h}{Packages/batch} = [\frac{batch}{time}]$$

To understand the relevance of the measure it will be described from without a technical view in Figure 22. It is described with two different belt brakes (filled line=Belt brake 1, dotted line=Belt brake 2), both with the same performance that handle the same amount of packages per hour.



Time for min.batch size

Figure 22. Frequency of two belt brakes. One with variable acceleration (filled line=Belt brake 1), the other with constant velocity (dotted line=Belt brake 2)).

The diagram is schematic but it can be noticed that both belt brakes has the same area beneath the respective graph. The difference between them is the batch size e.g. the amount of packages that is transferred between each start/stop cycle of the belt brake. Belt brake 2 works with constant velocity (no acceleration) which has fewer requirements as it does not need to switch between motion and stationary. However, Belt brake 1 has to work a great deal to maintain the same throughput as belt brake 2. This is compulsory in all applications where a batch of packages is used. The reason why the *frequency* measurement is applied is to consider both the amount of packages per hour that is transferred and to involve the *acceleration* of a belt brake, depending on the different requirements of the continuous and the accelerated belt brake which is set by the *minimum batch size*. If a belt brake works continuous it should have a minimum batch size that is infinite as it will not start/stop during run. To include the time it takes to accelerate the belt brake up to the constant speed it is considered to have a minimum batch size of 10 which means that it will start/stop each ten packages. When the minimum batch size is 1 it is required to start/stop each time a package is passing through. These attributes are considered as fundamental for the belt brake to work. It shall also be mentioned that it is much easier to establish a valid value on the *frequency* compared to the acceleration because the *packages per hour* is set by the production line and is available and the engineers are well familiar with the *minimum batch size*.

- **Minimum capacity**

Now that both the packages and the frequency are considered, it is interesting to know if there are more significant attributes for the belt brake. The packages arrive at a certain speed and are fixated by the belt brake that separates them into a certain batch size. How many packages are transferred through the belt brake? The capacity is set by the filling machine in the beginning of the line and depending on what filling machine that is applied in the production line the capacity varies. The capacity is a fundamental constraint that must be fulfilled in order to meet the requirements of the filling machine. The *minimum capacity* was chosen as the third significant attribute to also consider the amount of packages per time unit that is transferred through the belt brake and is defined as:

$$Minimum\ capacity = Nominal\ capacity * Safety\ factor * Over\ capacity$$

Each machine has a nominal capacity that has to be fulfilled to meet the filling machine performance. A machine that is designed has an extra built in over capacity to be able to work at a higher pace than the filling machine. The over capacity is needed when the line have had any downtime and the accumulator have to be emptied. The safety factor is a possible extra over capacity that if applied would be used to meet future requirements of higher speeds. The safety factor is not considered during this thesis since such plans for increased speed is not known. These values results in a minimum capacity throughput of packages per hour that is fundamental for the machine to meet the needs requested. As the belt brake is located within a machine the minimum capacity for the machine also concerns the belt brake.

However there are two other factors in addition to the significant attributes to consider in the clustering activity.

- **Sold units per year**

The number of belt brakes that has been sold to the market the last years varies a lot depending on usage. A few of them is offered as a service for the customers and is not selling more than a small number each year, approximately 5 per year. Others are implemented in newly developed machines that sell several each year, approximately 200-500 per year. The *sold units* per year are a relevant factor for evaluating clusters since sales statistics affect the possible winnings of standardisation. For example, if a brake sells in very limited numbers it will be very expensive since a few produced brakes will have to carry all the costs a brake gives rise to during its lifetime.

- **Manufacturing cost**

Finally, when the other significant attributes has been evaluated, the manufacturing cost of a belt brake is taken into consideration to assess the trade-offs between the belt brakes within the different clusters. The cost is the most driving of all significant attributes due to predetermined budgets for projects and is often the final settlement in decision making.

It was essential to gain reliability in the values collected and to confirm it by discussing the values with stakeholders that were independent from each other. The most difficult part was to collect the cost of the belt brakes due to variation of what was included in the values. The authors realised that these values are very important for the analysis to be right else the results of the clusters will be misleading. The values received from stakeholders were very fluctuating regarding sold units and cost and the reliability were not satisfying. An example is the standalone machines such as divider and converger where the cost of both the belt brake and an external electrical cabinet is included, which more than doubled the cost for the belt brake. The same thing happened when the amount of sold units were requested, stakeholders gave intuitive estimations as answers which could be discarded when statistical information was received from the internal systems. To maintain a methodical approach the authors requested all the information about sold units and price from Tetra Pak's statistical information system, including the comparable content.

Step 3

The final part of the collecting needs activity was to send out a questionnaire to chosen internal customers or stakeholders to confirm the data collected. The aim was to send the questionnaire to chosen stakeholders consisting of three persons per present machine; one technical manager, one mechanical designer and one automation engineer. As it in some cases was hard to find one representative from each position one fourth position was chosen, because there often was more experienced persons in the area. The fourth position, called technical expert can originate from different positions, but is often the project manager for the machine in focus. The fourth person functioned as a back-up, making sure there always were three respondents per machine. As there are 13 active machines the questionnaire was send to 39 different internal customers. The aim was naturally to receive 39 filled questionnaires but the authors realised that this 100% answering frequency was unlikely to receive. An acceptable answering frequency was set to 67% which responds to receiving at least two questionnaires per machine. The reason to the expected answering frequency's rather low share is based on this thesis relatively low priority. It is also possible that the respondents more or less forget to answer as they probably receive a lot of e-mails every day with higher prioritised issues and as these are handled the questionnaire are forgotten. If this limited answering frequency is considered already in an early stage it is easier to affect it in the positive direction. This was done by sending out two reminding e-mail to challenge the respondents by setting deadlines for hand in of the questionnaire. After these actions to improve the answering frequency, the case was closed and the collected information could be used in the further activities.

The questionnaire serves three purposes.

- To weight the collected needs.
  This makes it possible to assess the stakeholder's evaluation of the importance of each need.

- To confirm the needs collected during interviews.
  This is basically an act to validate the reliability of the needs collected.

- To complement with application specific functions or requirements.
  The last opportunity to catch the voice of the stakeholder before handling the collected information.

The questionnaire was composed as an excel sheet, see Appendix B – Questionnaire Belt Brake. To force the respondents to fill in a special range of numbers, drop down lists were used and clear notes declared how to fill in the form. There are many ways to weight the needs and many ways were considered. A common way is to let the respondent use numbers between 1 and 10 and let the numbers be reused as many times as the respondent likes. This way to weight will on one hand normally result in more significant variance in the answers, but on the other hand will all respondents use different amount of given points and thereby will their answers have a bigger influence in the total. To cope with this issue the authors chose to let the respondents give away only one number of points to one need. In this way the respondent will have limited total number of points, in this case 91 points, 13+12+11…+1=91. With this method the advantage that the respondents will be forced to prioritise the needs internally overtakes the withdraw that the variance will be less significant. The fact that the variance is limited must be considered in the further activities as the weighted results will be further handled.

The needs that were weighted in the questionnaire were the 13 most important needs collected through previous interviews. And in the same questionnaire the significant attributes were confirmed. To force the respondents' to fill in a special range of numbers drop down lists were used and clear notes stated how to fill in the form.

6.3 Cluster present elements into one or more groups

Choosing the clustering method

To choose the best way to cluster the present belt brakes into groups with similar requirements a few methods were developed. The methods were compared to each other and the best methods were selected.

The developed methods are briefly described below.

1. **Product of significant attributes**
   The three significant attributes p*ackage volume*, *minimum capacity* and *frequency* were multiplied for each belt brake to obtain a product index that, in an easy way, can be compared for all the belt brakes. The motive of using this method is that the variation of the product index is distinct on high values.

2. **Family/portion**
   A natural method to divide the clusters in is the *volume* of the packages. As there are distinct limits of the element specifications for family packs (>1L) versus portion packs (<1L) this might be a good clustering method.

3. **Flex/Speed**
   Another natural clustering method is to use the distinct specification of *speed* to cluster the elements that is divided into either speed (up to 24.000 packages/h) or flex (up to 9.000 packages/h).

4. **Scoring system**

If more than one significant attribute is chosen to represent the elements they can be evaluated by using of a *scoring system,* see Table 2. The motive of using a scoring system is to take all significant attributes into consideration at the same time resulting in a score-based result for each element. In that way the methodical, numerical way can be achieved. The method works from the supposition to divide all belt brakes into different numbers of cluster. In the example in Table 2 *2, 3,* and 4 clusters are used. The clusters are divided only considering one significant attribute at a time. Then the clusters are ranked in level of performance. When 3 clusters are used for example the cluster with the most demanding performance will gain 3 point, the middle cluster will gain 2 points and the cluster with least demanding performance will gain 1 point. This rating is performed for every significant attribute and different number of clusters. As the rating is performed, the score are summarised for each belt brake.

	Significant attributes				*Machine Elements*					
	Speed	Frequency	Pack. Volume		E1	E2	E3	E4	E5	E6
Nr. Clusters	S2	F2	P2	→	3	3	5	6	7	8
	S3	F3	P3	→	5	9	7	4	3	1
	S4	F4	P4	→	5	9	8	3	10	7
				→						
				→						
				SUM	13	21	20	13	20	16

Table 2 Comparable analysis tool resulting in a scoring system.

5. **Normalised sum of significant attributes**

This method was applied to combine the three significant attributes p*ackage volume*, *minimum capacity* and *frequency* into a common sum index that makes it possible to compare the belt brakes to each other. The power of this method is within the variation that is apparent for the belt brakes with low values. To calculate the index it was necessary to normalise the values for each significant attribute to make them comparable. It was completed by dividing each belt brakes value with the top value of all belt brakes. The result was a value between 0 and 1. When the calculations were completed the three normalised values for each belt brake were summed into the normalised sum index. A diagram of the normalised sum index can be seen in Figure 31 in Appendix G – Result of normalized sum and product.

6. **Single attribute step ratio**
   The aim of the method was to observe the *variation* between the belt brakes by each of the selected significant attributes and identify the belt brakes that have the most similar performance. A diagram was created over the diversity of each attribute to visualise the values for the different belt brakes. The diagram can be seen in Appendix E – Significant attributes results 2 (2).
   The package volumes were first evaluated by putting the package volumes in ascending order and calculate the ratio between the second and the first value. The ratio between the third and the second were then calculated and the calculations followed this pattern for the rest of the belt brakes. This will be useful to understand where the *boundaries* are located within the specifications of today's belt brakes. It can be seen in Figure 28 in Appendix F – Results from single attribute step ratio 1(2) that the belt brakes that are located on the same line can handle the same package sizes e.g. no differences. The marked spots are three distinct variations in handled package sizes. If the package size would be the basis for the clusters there would possibly be three potential clusters consisting of the belt brakes that are located on the same horizontal line as they have the same requirements. The belt brakes that are located in between the distinct clusters (marked with circles) has to be put within these clusters or if necessary create own clusters just for them. The belt brakes marked with a square has a sales statistics of less than 10 belt brakes per year. It is essential to include these in a cluster since the cost for producing few belt brakes are higher and provides no economies of scale. Both the *frequency* and the *minimum capacity* were calculated analogy and are shown in Figure 29 and Figure 30 in Appendix F – Results from single attribute step ratio 2(2).

7. **Pure intuition**

   The method of pure intuition is a completely practical method where the stakeholders use their experience to cluster the elements without the use of any basic data as support. The method is recommended for use only when few elements shall be clustered as the complexity grows when taking more elements into consideration.

How can it be possible to cluster the elements? The authors have evaluated the seven different clustering methods described above to find the best solution that can divide elements into clusters with help of the Pugh concept selection, see Table 3.

Criteria	Concepts						
	Product (Reference)	Famiy/ Portion pack	Flex/ Speed	Discrete	Normalised Sum	Single attribute Step ratio	Pure intuition
Ease of use	0	+	+	-	+	-	+
Accuracy	0	-	-	-	0	+	-
Sensitivity for variations in indata	0	-	-	-	0	+	-
Consider many variables	0	-	-	+	+	-	0
Methodical/ Scientific	0	-	-	-	0	+	-
Number better: S+ Number worse: S- Number same: S0	0 0 5	1 4 0	1 4 0	1 4 0	2 0 3	3 2 0	1 3 1
Net score	0	-3	-3	-3	2	1	-2
Rank	3	5	5	5	1	2	4

Table 3. Pugh concept selection for choosing the best clustering method. The three concepts that were ranked as the best are marked in the table.

One concept was put as reference, in this case the product concept, and the other concepts were then evaluated on the criteria on the left. Each concept could be assigned either a plus (+), minus (-) or a zero (0) for the criteria.

The criteria are described below:

- **Ease of use**

  The ease of use describes the *time* and *effort* that is required to calculate the results of the concept.

- **Accuracy**

  The accuracy enlightens how powerful and helpful the concept is to visualise results to be used as a support for clustering.

- **Sensitivity for variations in in-data**

  This criterion describes how a change in the in-data affects the method. It gives an idea about the spread of the method measurement.

- **Consider many variables**

  To create clusters it is of importance that the vital variables are considered. The criteria shows how concentrated the concept are regarding the amount of variables considered.

- **Methodical/scientific**

  The grade of scientific work behind the concepts.

When the criteria were evaluated the assigned values were summed and a total score was achieved. The concept selection resulted with the *normalised sum, single attribute step ratio* and *product* as the three methods with the highest ranking. The motive of the result is that the combinations of the three methods with highest ranking complement each other in visualising the variance of the significant attributes for each belt brake. The advantage of the product and normalised sum concepts is that they are very easy to generate and gives a result that is facilitating when analysing the belt brakes. Together with the single attribute step ratio a further methodical approach is applied that visualises the difference between the belt brakes performance. The family/portion and flex/speed were not reliable concepts to cluster on since they only cover a narrow area of the total requirements that has to be taken into consideration. The discrete concept were a good system for evaluating many variables since the performance is translated into points but it also requires a lot of effort compared to the winning concepts and includes a slight intuitive approach. The pure intuition concept is easy to use if experienced stakeholders are present except from that the grade of scientific approach is considered as low since no data will be used for support when clustering.

6.3.1 Establishing natural clusters

The identified significant attributes were positioned on the x-axis of a matrix together with the identified belt brakes on the y-axis, see Appendix E – Significant attributes results 1 (2). When the values were collected an analysis was performed on the significant attributes with the three selected methods from Pugh concept selection.

In the following pages each belt brake is divided into natural clusters together with a brief discussion. It will be easier to understand the upcoming analyse if the results are studied in parallel, see Appendix F – Results from single attribute step ratio 1(2) *and Appendix G – Result of normalized sum and product.*

Cap Applicator 30 Speed (CA 30 S)

As the three methods have different strengths and weaknesses, they were used together to complement and support each other. The origin point was the two methods *normalised sum-* and *product of significant attributes that were* used to get an overview of the total requested performance for the belt brakes. As the TS 30 requires most overall performance, this machine is compared with the second most overall requiring machine, CA 30 S. When these machines are compared on the single attributes alone it comes clear that they diverse a lot, especially when handled package volume is compared, but there are also significant differences in the frequency measure. This is especially clear in the cumulative *single attribute step ratio diagram*. After this comparison it is clear that CA 30 S and TS 30 will possibly not end up in the same natural cluster.

Cardboard Packer 30 (CBP 30)

The comparison now moves to the next belt brake in the overall performance analysis. CBP 30 is next in both overall performance analyses. In the single attribute step ratio diagram a difference in minimum capacity is noteworthy, also in frequency there is a difference. After tracing the differences to its roots it is realised that the differences in minimum capacity is discussable. As CA 30 S only handles 1000ml the nominal capacity is set to 15000 pph as this is the maximum speed for the filling machine at this package volume. This explains the disparity in minimum capacity for the two machines, but as CBP

30 has capability to handle smaller packages at a higher capacity it is possible to use the same belt brake in CBP 30 as in CA 30 S. The difference in frequency is considered as negligible. These two belt brakes will from now on belong to the same natural cluster, named cluster 1.

Multi Shrink 30 Belt brake and pusher (MS 30 BB and MS 30 P)
After CBP 30, the two overall performance analyses diverse, however the two types of belt brakes in MS 30 that only handles portion packages were compared together against the so far created cluster. The brakes are named MS 30 BB and MS 30 P and have the exact same values of their significant attributes as they handle the exact same packages in the exact same way. Compared to CBP 30, these brakes have to meet the same level of minimum capacity and almost the same level of frequency, though the size of handled packages differs. There is however reasons to keep the brakes in cluster 1 since MS 30 was from the beginning developed to handle up to 1000 ml packages and it is likely that it one day will be able to do this. This means that even MS 30 P and MS 30 BB will be included in cluster 1.

Divider 122
As the conveyor brake differs a lot on the frequency requirement this brake was disregarded for now, the divider 122 brake was then next in turn to be evaluated. The divider brake handles, as CA 30 S and CBP 30 packages up to 1000 ml volume and can also run portion packages at a nominal capacity of 24 000 pph. The requirement in frequency is not as high as for the other brakes already in this cluster, but as the divider is sold in a small amount every year the total cost to use a brake with higher performance than needed will thereby be negligible. The divider 122 will thereby take place in cluster number 1.

Converger 221
Together with the Divider 122 comes the Converger 221. They have similar significant attributes, possibly because of their functions are similar. As all significant attributes are more or less the same it is also natural to keep these two together in the same cluster, which even for the Converger 221 will be cluster 1.

Conveyor

The belt brake owned by the conveyor group, also called conveyor handles packages larger than the ones in cluster 1 but with the same speed. As there are no strict requirements for the frequency this brake is chosen to be kept in a new cluster, cluster 2. Another reason to keep this brake in a new cluster is because of the sales statistics. This brake is the most selling brake of all and any unnecessary overcapacity would impact the total cost more as the sold units is high.

Film Wrapper 68 (FW 68)

The FW 68 belt brake has similarities to both cluster 1 and cluster 2. It handles packages of a volume up to 1500 ml, the frequency is similar to CBP 30 and MS 30 in cluster 1 and the minimum capacity is approximately 16000 pph. This belt brake is put in cluster 1 even though it will impact the need for performance on the other belt brakes in that cluster. As it handles packages up to 1500 ml all brakes in the cluster will have to gain some overcapacity but only the need to handle a heavier product as the package Tetra Brik Aseptic 1500 Slim have the same limiting dimension as Tetra Brik Aseptic 1000 Square. This on the other hand will be compensated in the FW 68 as it requires a lower performance in speed, due to the lower minimum capacity.

Cardboard Packer 32 (CBP 32)

CBP 32 has no straight forward position in the already created clusters. It handles a wide range of packages, both according to shape and size. There are no extraordinary requirements of either frequency or minimum capacity, though the intermediate frequency requirement together with the requirement of handling up to 2000 ml packages will make it a good candidate to create its own cluster. As this is done it will be the third created cluster referred to as cluster 3.

Multi Shrink 30 Unit Conveyor (MS 30 UC)

The unit converger, MS 30 UC, used after the multi shrink to put the filmed packages on one conveyor, is similar to the package converger 221 in frequency. But as the MS 30 UC handles units up to 3000 ml and must be able to operate at a frequency not far from the CBP 32, it is placed in the same cluster as the former, cluster 3.

Straw Applicator 30 (SA 30)
The SA 30's requirements for a belt brake above are all driven by the significant attribute minimum capacity. It has no strict requirements in frequency or package size. This is reflected on the present technical solution that consists simply of two rotating wheels. Because of the low requirements in frequency but still reasonable requirements in the minimum capacity it will fit into cluster 2.

Package Turner 100 (PT 100)
The requirements from the package turner application PT 100 are similar to the requirements originating from the SA 30, though the significant attributes derive. As it alike the conveyor belt brake must be able to handle packages up to 2000 ml and have low requirements in frequency it will fit into cluster 2.

Cap Applicator 30 Flex (CA 30 F)
CA 30 F is according to the overall performance analysis one of the applications that put the least requirements on the belt brake. It operates continuously and must only be able to operate at low minimum capacities. Though, it must be able to handle packages up to 2000 ml. These requirements make it fit into cluster 2.

Film Wrapper 32 (FW 32)
The last application to fit into a cluster is FW 32. As it only handle packages up to a volume of 375 ml and operates at a low minimum capacity, the driving attribute will be frequency. These requirements make it possible to place FW 32 in both cluster 1 and cluster 3. The applications in cluster 3 do not have high requirements for minimum capacity and FW 32 will therefore be a natural member of cluster 3.

Tray Shrink 30 (TS 30)
As TS 30 was left alone in the beginning of this activity according to the special requirements it is decided to be kept as it is which will thereby create cluster 4.

Commentaries to natural clusters

CA 30 S has the highest requirement in frequency; this is due to the collected need for this brake, requesting a minimum batch size of 1 package. In the present solution this brake is similar to the CA 30 F brake, which does not request any requirements of handling batches but rather are required to operate continuously. If this diversity in required performance has risen from bad quality in in-data or it is reflecting the real requirement is not clear. However the brakes are handled in a methodical way, which will put them in different cluster.

A possible alternative is to combine the two convergers and use the same brake in both MS 30 UC and converger 221. This alternative might be further evaluated and kept in mind to the concept development. TS 30 and CBP 32 have similar belt brakes in the present solutions, which could tell us something about the complexity and difficulties with clustering on the significant attributes. Or it might be an example of the weakness of the present way to copy solutions and then modify them until they operate properly. Another unexpected difference is that divider 122 and conveyor belt brakes were found in different natural clusters. These two brakes are almost identical, but as they perform different duties, their requirements are different. This could be the result of uncertain accuracy in the method, or it can be seen as the potential to use more versatile belt brakes, as the described brake actually is capable of performing different types of performance.

The results of the natural clusters are shown in Table 4.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
FW 68	Conveyor	CBP 32	TS 30
CA 30 S	PT 100	MS 30 UC	
CBP 30	SA 30	FW 32	
MS 30 P	CA 30 F		
MS 30 BB			
Divider 122			
Converger 221			

Table 4 Natural clusters

6.3.2 Establishing potential clusters

The natural clusters are shown in Table 4 and it is time to decide if they will be kept this way or if it is possible to merge the clusters or maybe even split them into additional clusters. There are huge numbers of theories describing how to make a decision. It could of course be an advantage to use one of these, especially if the one utilising this method already are familiar with such theories. The authors consider this kind of methodologies to be outside of the limitations for this thesis and have chosen to make this decision upon a short analysis. The analysis will include the impact of tradeoffs, economical estimations and potential advantages and risks.

By reducing one cluster will decrease the total lifetime cost that is further discussed in chapter 7.Though, it is likely that the more brakes included in a concept, the more complex will the concept be and the bigger effort have to put in the development, which is equivalent to higher costs. It is also likely that a complex concept will consist of more articles and this will lead to increased lifetime cost per cluster. Another risk worth to mention is that as the complexity of the developed concept increases the reliability and robustness may be harder to accomplish, or even decreased. After this short reasoning it is decided to leave the clusters as they fell out from the natural clustering activity, but this reasoning is valuable to bring when the concept development activity takes over.

6.4 Establishing target specification

After the potential clusters of present belt brakes where set, the work to establish a common target specification covering all the needs arising from these applications could start. The weighted needs collected from the different stakeholders in an earlier activity where now in centre. The needs weights were inserted in the HOQ and the relative weight were calculated.

For every need, a related engineering attribute have been defined. The engineering attributes are defined in Appendix I - Applied engineering attributes*. The transformation of customer needs into engineering attributes is described step by step below.*

Work continuously with few stops

To satisfy the customer need “work continuously with few stops” a robust design is required. On the other hand robust design is impacted by many other needs but also by many other engineering attributes. The most straight forward way to measure how continuous the element works is by the *MTBF* measure. As *MME* is dependent on the MTBF measure it will also be dependent on the need to work continuously with few stops. Fewer stops will of course impact the production cost and it is dependent on the brake to handle packages with straws and a varying size and shape of the packages, which makes an impact on the package tolerance.

Capable of handling long queues

As one of the functions of the belt brake is to handle the queue in front of a machine it is a natural need to be asked for. There are many ways of measuring the ability to handle queues e.g. force (N), number of packages and length of the queue in meters. To keep the engineering attribute as practical as possible the *length of the handled queue (m)* is chosen in this thesis.

Low (planned) maintenance

The need for low maintenance is basically connected to the cost, both for the actual maintenance activity but also to the cost for missed production. To measure the amount of maintenance the engineering attribute *Preventive Maintenance Time /1000 Production hours* have been used.

Short changeover time

The need for short changeover time is straight forward connected to the *changeover time*. To accomplish an element for which changeover is easy to perform it is likely that the *dimensions* will be affected.

High accessibility

It is chosen to relate the requirement in high accessibility to the engineering attributes connected to the size of the element, which in this case will be the *footprint* and the *dimension* of the brake. The accessibility is also related to the time it takes to recover or repair the brake.

Low energy consumption
The need for low energy consumption is straight on. It is natural to keep the energy consumption as low as possible, and the engineering attribute related directly to this need is energy consumption. The energy consumption attribute is also a part of the Maintenance & Running Cost/1000 packages. It could be merged into this attribute but is chosen to keep separate as it then is possible to set a specific target for this attribute.

Low operational cost (Euro/1000)
Low operational cost could be seen as related to many engineering attributes, and especially many different costs that is summarised in one common cost named *Maintenance and running cost per 1000 packages*.

Low waste of packages
Product efficiency is a measure of how many of the handled packages that is discarded; it is basically a measure of the percentage of the correct handled packages. The degree of wasted packages also affects the production cost, but should normally have small influence of that cost.

Small footprint
Small footprint is as much an engineering attribute as a product attribute. It often origins from the present applications but is also of great importance to consider as the floor area is directly connected to costs and floor area can be very limited for some customers.

Manufacturing cost
The manufacturing cost is as the footprint measure both a product attribute and an engineering attribute. It is though related to more engineering attributes. The elements lifetime is affected and so are the engineering attribute *commonalities with other belt brakes*, as handling fewer articles will lead to lower costs.

Designed using standard elements
It is natural that the customers prefer the machines to be composed using standard elements as it brings advantages in term of easier spare part handling but also makes it easier for the operator to recognise the parts. To

achieve this in a design process it is important to set targets in an early stage. This is the reason to why the engineering attribute *commonality with other belt brakes* is implemented. There are other aspects of this need, as the aim to use commercial standard elements. Tetra Pak already have global targets for this attributes and have thereby disregarded this aspect. It is a fact that the use of common articles will lead to profits when it comes to manufacturing costs and this engineering attribute is thereby related to the need discussed.

High robustness

To meet this need it is important to use the robust design process. The earlier in the development process it is used the better the robustness result can be. Robust design experiments can be used within the concept development phase as a way to refine the specifications and set realistic performance targets.

Simple design

Simple design can be measured in different ways; it is chosen to use the engineering attribute *number of articles* to correspond to this need, even though the complexity of the articles is then not considered. It is assumed that as the need simple design and the target value for the *number of articles attribute* will be stated in the target specification, there are no designer that will make the articles more complex than needed

7 Cost analysis

A cost analysis has been conducted to support the proposed process and its advantages in cost savings. In this chapter the results of this is shown and what variables that affects the cost.

The outcome from the developed standardisation process impact the total costs. The fact that standardised machine elements will give rise to less unique articles is the basic reason to how the costs will be impacted. As described in chapter 3.7, an article is defined as a part of a machine element.

To determine how big impact less unique articles will have on the cost, the root causes of the costs were discussed and the conclusion was stated in the two most important costs, *lifetime cost* (including *commonality index)* and *manufacturing cost that* will be described.

Lifetime cost

Lifetime cost is the administrative cost an article gives rise to during its lifetime, it is further described in chapter 3.7. At Tetra Pak the lifetime of an article is set to 20 years. The lifetime cost is built up of five administrative costs that are shown in Figure 23.

	One time impact when developed/ introduced	Annual cost while in production	Annual cost while in installed base
Development	€XXXX	-	-
Engineering	€XXXX	-	-
Purchasing	€ XXX	€ XXXX	-
Spare part administration	-	-	€ XXX
Service	€ XXX	-	€ XXX
Total per year	€ XXXX	€ XXXX	€ XXX
# of years	1	10	20
Total over lifetime	€ XXXX	€ XXXXX	€ XXXX

Lifetime cost per unique part: € XXXXX

*= Source: Study conducted by GTS; Bain estimates

Figure 23. Description of Lifetime cost.[57]

[57]GTS (2004), *Bain estimates*, Tetra Pak

The largest costs are introduced the first year while the remaining costs consist of maintaining the article. The mean lifetime cost per article results in XX.XXX €. The study is conducted for the articles in the filling machine and the authors assume that the cost can be applied also on the downstream equipment.

As the lifetime cost is the cost to administrate a single article during its lifetime, the decrease of unique articles will decrease the total cost in a linear ratio. Though, the complexity increases as every reduced belt brake give rise to increased requirements for a standardised belt brake. This is approximately visualised in Figure 24. The complexity can consist of increased number of articles in a standardised belt brake and also adjustments to a number of machines which will require more effort in development.

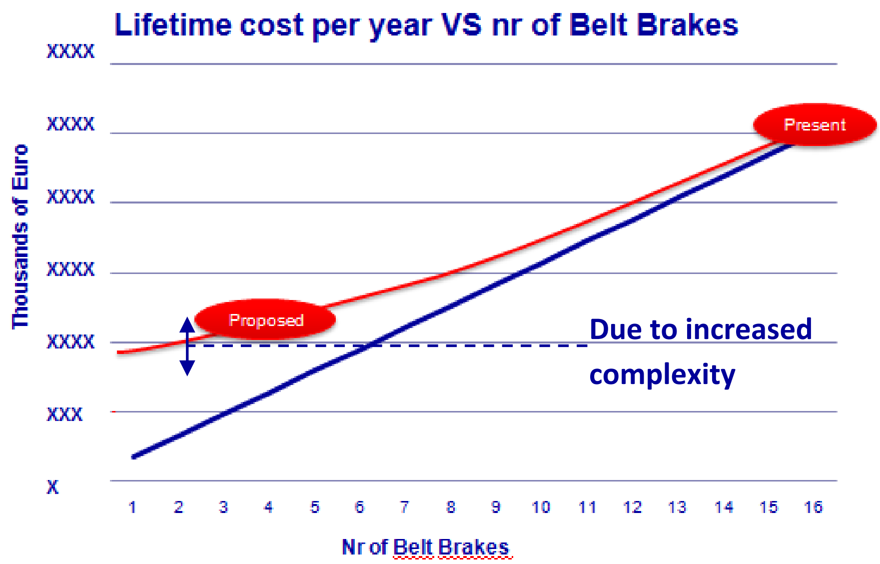


Figure 24. Linear ratio between Lifetime cost and the number of belt brakes

How many articles can be reduced by clustering and what are the potential in cost savings?

By applying the belt brake as the machine element in the process, 16 belt brakes were clustered into 4 clusters which is a reduction of twelve belt brakes.

An empirical study was performed to locate the amount of articles that were included in a belt brake. The article list of two belt brakes, CA30 Flex and Conveyors, were collected from PIV and a mean were calculated to 124 articles/ belt brake. The commonality was also calculated between these two brakes and one additional brake (converger) and resulted in an average commonality of 10 %. Thus there are approximately 112 unique articles per brake. Together with the lifetime cost (Bain) of XX.XXX€/article[58] over a period of 20 years a mean belt brake will have a cost of X.XXX.XXX€/ 20 years.

As the amount of belt brakes will be reduced by twelve, this will result in a potential reduced cost of 12*X.XXX.XXX€ =XX.XXX.XXX€/20 years, or X.XXX.XXX€ annually. This cost reduction is the one that the process potentially will give raise to. The project to standardise the elements shall be covered in this cost, else there is no potential of reducing the cost for Tetra Pak. It shall also be mentioned that this cost reduction will not affect immediately since the present belt brakes are totally retired.

By introducing commonality *index* together with clustering a commonality between the new clusters can further reduce the number of unique articles. In that way, a solution where articles are reduced both by clustering and by using articles that is common between the clusters can reduce the lifetime cost. Figure 25 visualises the commonality between three clusters, where the unique article only is counted in cluster 1. The other two common articles in cluster 2 and 3 are not carrying any administration costs. The way to calculate the commonality differs, though an empirical calculation has been completed between CA 30 F belt brake, converger belt brake and Conveyor's belt brake which resulted in an article commonality of approximately 10 %.

Figure 25. Cost reduction by applying commonality. Three Clusters, seven unique articles.

58 GTS (2004), *Bain estimates*, Tetra Pak

It can be seen in Figure 26 that the combination of reducing clusters and increasing commonality will reduce the total cost. The more amount of clusters that is selected, the more impact does the commonality have on the cost reduction. It means that a trade-off has to be applied to find the best solution of amount of clusters and commonality. In the final HoQ the authors has chosen to set a target commonality of 50% to motivate the employees of raising present commonality. The target should of course be to keep the commonality as high as possible as this will lead to fewer unique articles and in its turn reduced lifetime cost.

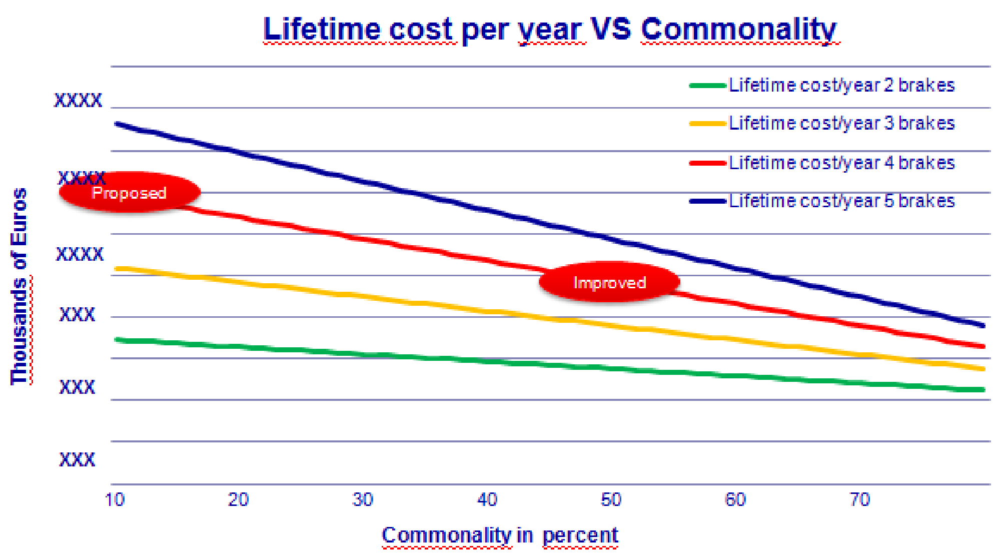


Figure 26. Lifetime cost (Bain) VS Commonality.

The result of the commonality investigation showed that the common articles between the compared brakes were basically screws, nuts, washers and such small and simple articles. To use the same screws will not give rise to cost reduction to the extent described above, but if larger drawn articles and commercial articles will be reused in different belt brakes, the calculations above will be more accurate. There is also a possibility to reuse some assembled parts (sub modules) between the belt brakes, which will give rise to even higher commonality. While calculating the commonality of articles in percent the matter of what type of article that is common will not be considered, but as mentioned in chapter 3.5 there are other ways to calculate the commonality which are able to handle such matters.

Manufacturing cost

The manufacturing cost is the cost it takes to produce the article; or rather the cost Tetra Pak has to pay the supplier to receive the article in question. The manufacturing cost impacts both the cost when the machine is installed and also when spare parts are purchased. Due to economies of scale the manufacturing cost will decrease as the number of unique articles is decreased. The explanation for this hypothesis is that as the number of unique articles is decreased, the remaining articles will sell in larger amount. How large the potential economies of scale might be, is hard to estimate. Such estimation should probably be best performed by the supply chain department.

8 Concluding remarks

This chapter reflects the conclusions that the authors have drawn from without the results of this thesis. The conclusions will answer the purpose and act as indicative in further work with the proposed process.

During this thesis a process was proposed to describe how to approach a standardisation of common elements. The proposed process describes one general solution of the standardisation problem and *may* be refined for use in other sector of applications. The process shall act as a support when to approach the standardisation problem.

8.1 Proposed process

- The authors recommend that a theoretical approach is applied to create clusters of elements. This is to maintain an objective view of the elements' requirements and to keep a methodical approach. The results of the target specification will be applied as a support for the stakeholders when using intuitive methods to complete the potential clusters.

- During this thesis it has been well known for the authors that all stakeholders were important to identify in an early stage. However, new stakeholders have been identified at a very late stage in the applying step which even more clarifies the importance of the identification activity.

- The approach to decrease the number of requirements to a few significant attributes while clustering the brakes have both strengths and weaknesses. It makes it easier/possible to compare many elements in an efficient way but at the same time there is a risk of not consider certain attributes. For example, the significant package volume. It considers the different volumes of the packages, but the different shapes of the packages are not taken into consideration. This type of simplifications must be used with the *understanding* of what requirements that will fall out during the use of them.

- While evaluating the potential clusters, it is of importance not to observe the present elements technical and design requirements as a constraint. They shall instead be observed from without tomorrows needs.

- An existing element may have unnecessary high performance in one specific application. This aspect shall not be taken into consideration in the clustering activity; instead the minimum performance shall be defined. The final performance may be affected by several different factors, such as higher performance target due to the product's roadmap, or a wish for extra overcapacity to improve the robustness of the product.

- The authors would like to introduce the *House of Quality* as a new standardised target Specification of Requirements document. The potential to have customer needs, engineering attributes, target values, correlation and a comparison between the elements in the same document offers a good quality overview for the next activity of concept study.

- It is of great importance that the extracting of costs for the elements is performed in a methodical way to ensure that the content of the cost is comparable between the elements. The authors had difficulty to find an equivalent cost that could be applied in the clustering activity as the costs varied a great deal. Instead, the annual sold units were applied. With a methodical way it is recommended to request one person to extract the costs in an equivalent way.

- While making trade-offs in the clustering it is important to bring *all aspects* into consideration. An example for this is when position the PT 100 brake in a cluster with present solutions that has more performance than PT 100. The fact that the present technical solution of PT 100 is of much simpler design than other brakes in the cluster might give rise to an increased manufacturing cost. It is to consider that the present solution fail the need to handle long queues and must be complemented with a hose brake. If developing a more advanced brake for the cluster that is able to handle the queues, the PT 100 will gain more performance than needed. Furthermore, the hose brake will be removed and the Bain cost saving for reducing the amount of articles will cover the cost of the extra performance of PT 100.

8.2 Economics

- A development of a new belt brake that meets the needs of more than one application must not necessarily be more expensive than a present belt brake that only is applicable in a single application. A detailed specification of requirement in the form of a HoQ promotes simple design which can reduce the total cost. It is therefore important not to consider the belt brakes cost today as a constraint when clustering, it shall instead be used as a comparison.

- Each time an existing article is copied into a new article number while designing an element the general thought is that the development cost is considered as zero and that Tetra Pak will reduce the overall development cost. Though, each copied article carries an administration cost of Bain that still will generate a high cost. It is therefore of importance that the employees are aware of the Bain cost and applies existing article numbers instead.

- If a customer that uses a simple element will be affected to change into a more advanced element after new clusters have been shaped, Tetra Pak can absorb that extra cost for the customer as long as it complies with the laws regarding competition. The effort in reducing the total cost for having one less cluster is a great deal higher than the extra cost that is created for the customer.

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Appendix A – Questionnaire Processes

- An example of project?
- How do you work with projects, which process is used in your work?
- Wherefrom comes the process?
- Why is the process used?
- How long has this process been used?
- Are there any efforts to improve the collaboration between the departments in Lund? Modena in Italy?
- What are the advantages/disadvantages of working with new/old process?
- If you had to change the process of working, what would be your first move?

Appendix B – Questionnaire Belt Brake

Machine (the answers shall be specific for this machine)	Converger 221
Respondent:	-
Title:	Technical expert

The following questionnaire serves three purposes.
-To weight the collected needs
-To confirm the needs collected during interviews
-To complement with application specific functions or requirements

Needs	**Weight needs** **13 = most important** **1 = least important**
Work continuously with few stops	1
Capable of handling long queues (3-5m)	2
Low maintenance	3
Short changeover time	4
High accessibility	5
Low energy consumption	6
Low operational cost (Cost/1000)	7
Low waste of packages	8
Small footprint	9
Manufacturing cost	10
Designed using standard elements	11
High robustness	12
Simple design (keep it simple)	13

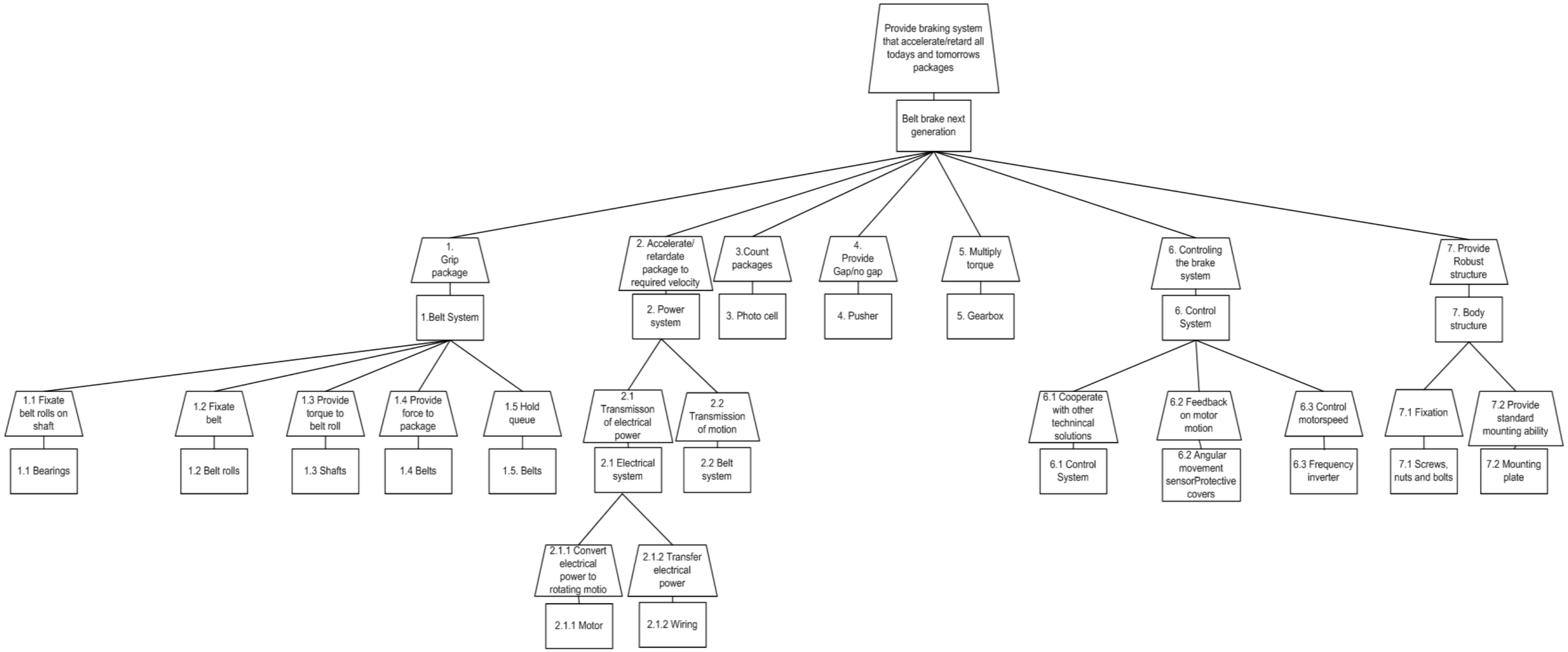
Engineering attributes/functions	**Define values**
Minimum throughput pph	
Minimum batch size	
Gap between released packages	
No gap between released packages	
Count released packages	

List specific needs not considered above

Appendix C – Stakeholder matrix

Department	Contact	Title	Skills in
Film Wrappers			
	X	Test Engineer	FW 32
	X	Automation Engineer	FW 32
	X	Technical Manager	FW 32
	X	Mechanical Designer	FW 32
	X	Test Engineer	FW 68
	X	Technical Expert	FW 68
	X	Automation Engineer	FW 68
	X	Test Engineer	TS 30
	X	Mechanical Designer	TS 30
	X	Technical Expert	TS 30
	X	Mechanical Designer	MS 30
	X	Automation Engineer	MS 30
	X	Technical Manager	MS 30/Straw A.30
Cardboard & Straw			
	X	Test Engineer	CBP 32
	X	Automation Engineer	CBP 32
	X	Technical Manager	Straw Applicator 30
Cap Applicator			
	X	Automation Engineer	CA 30 F
	X	Mechanical Designer	CA 30 S/Flex
Conveyor & Accumulation			
	X	Mechanical Designer	Conveyor
	X	Technical Expert	Conveyor
	X	Automation Engineer	Conveyor
	X	Technical Expert	Divider/Converger/PT100
	X	Project Manager	Divider
	X	Test Engineer	Divider
	X	Technical Manager	Divider/Converger/PT100
	X	Technical Expert	Divider/Converger/PT100

Appendix D – Function Means Tree



Appendix E – Significant attributes results 1 (2)

Belt Brake	Package volume [ml]	Frequency [1/s]	Minimum Capacity [pph]	Sold units/year	Over capacity	Minimum batch size
Conveyor	2000	0,87	31200	400	1,3	10
FW 32	375	1,00	10800	40	1,2	3
CBP 30	1000	2,89	31200	50	1,3	3
SA 30	500	0,87	31200	50	1,3	10
TS 30	12500	0,70	33000	200	1,375	
Converger 221	1000	1,06	30420	2	1,3	8
Divider 122	1000	0,96	31200	10	1,3	9
PT 100	2000	0,31	11250	5	1,25	10
MS 30 BB	250	2,89	31200	25	1,3	3
MS 30 P	250	2,89	31200	25	1,3	3
MS 30 UC	3000	0,96	10400	25	1,3	3
FW 68 -0400 (card inserter)	1500	2,22	15960	-	1,33	2
FW 68 -0600 (Double infeed divider)	1500	2,22	15960	10	1,33	2
CBP 32	2000	1,56	11250	250	1,25	2
CA 30 F	2000	0,29	10400	150	1,3	10
CA 30 S	1000	5,21	18750	25	1,25	1

Table 5. The results of the significant attributes collected in the activity of “collect needs and functions”.

Appendix E – Significant attributes results 2 (2)

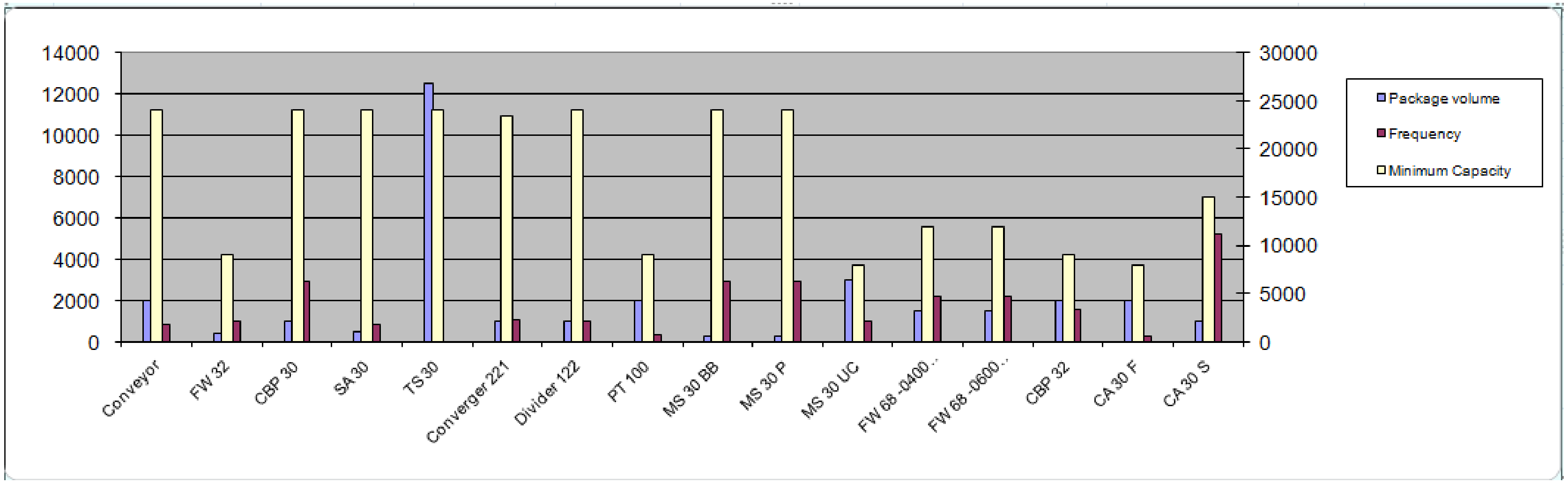


Figure 27. The significant attributes in a diagram. Note that the frequency has been multiplied by 1000 to be observed.

Appendix F – Results from single attribute step ratio 1(2)

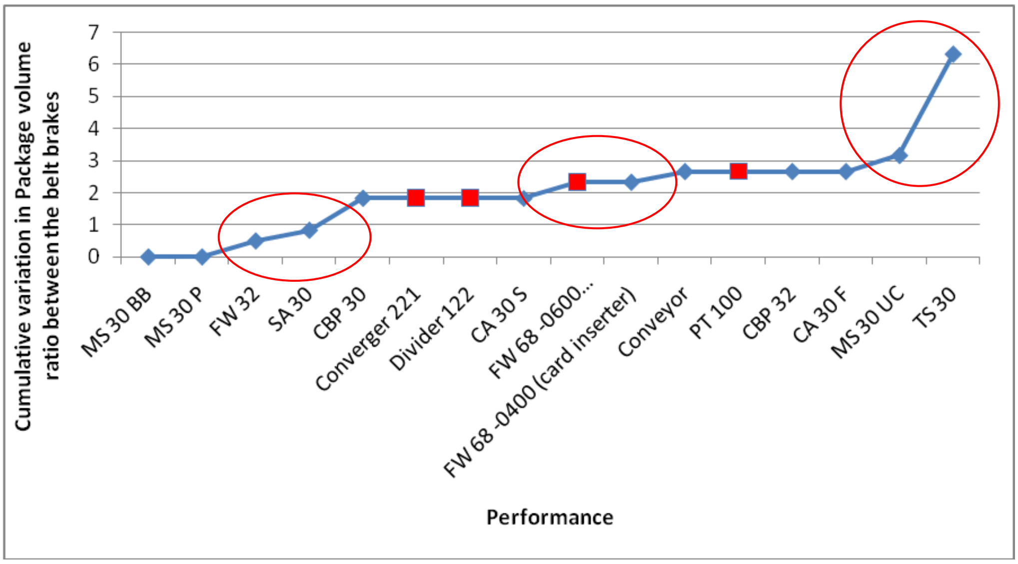


Figure 28. *Package volume*; the value describes a belt brakes performance ratio compared to the belt brake to the left. The belt brakes marked with a square has a sales statistics of <10 per year.

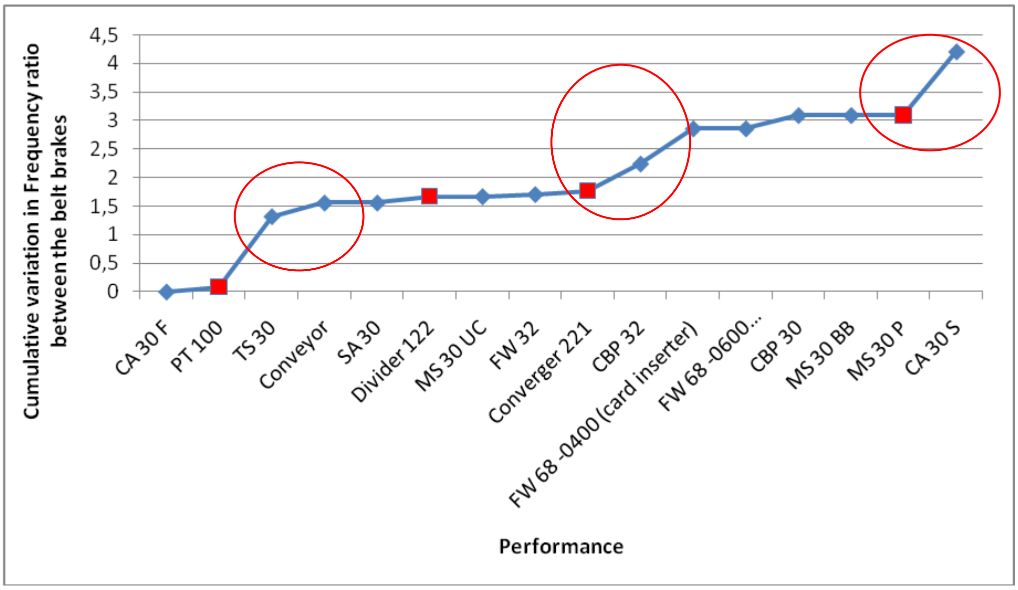


Figure 29. *Frequency*; the value describes the belt brake's performance ratio compared to the belt brake to the left. The belt brakes marked with a square has a sales statistics of <10 per year.

Appendix F – Results from single attribute step ratio 2(2)

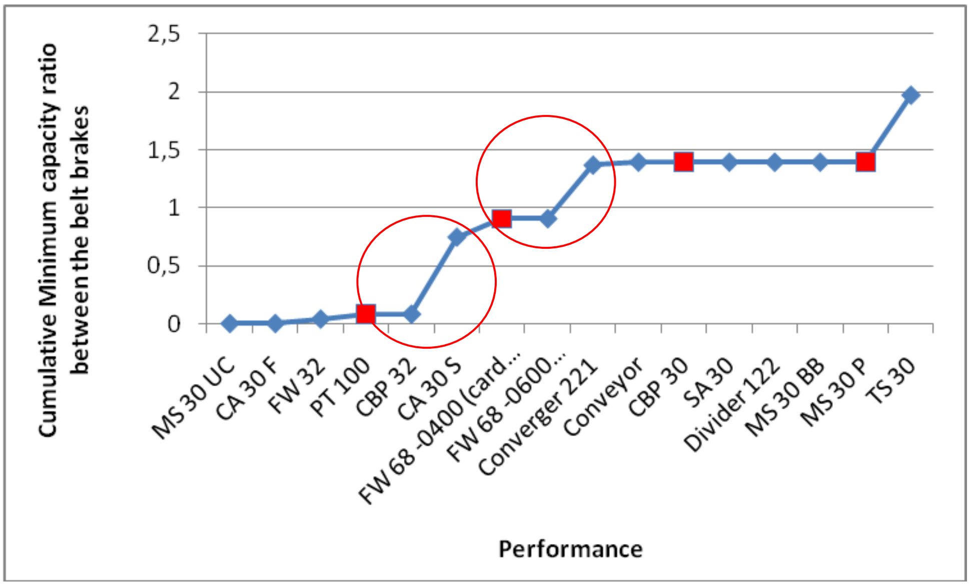


Figure 30. *Minimum capacity*; the value describes a belt brakes performance ratio compared to the belt brake to the left. The belt brakes marked with a square has a sales statistics of <10 per year.

Appendix G – Result of normalized sum and product

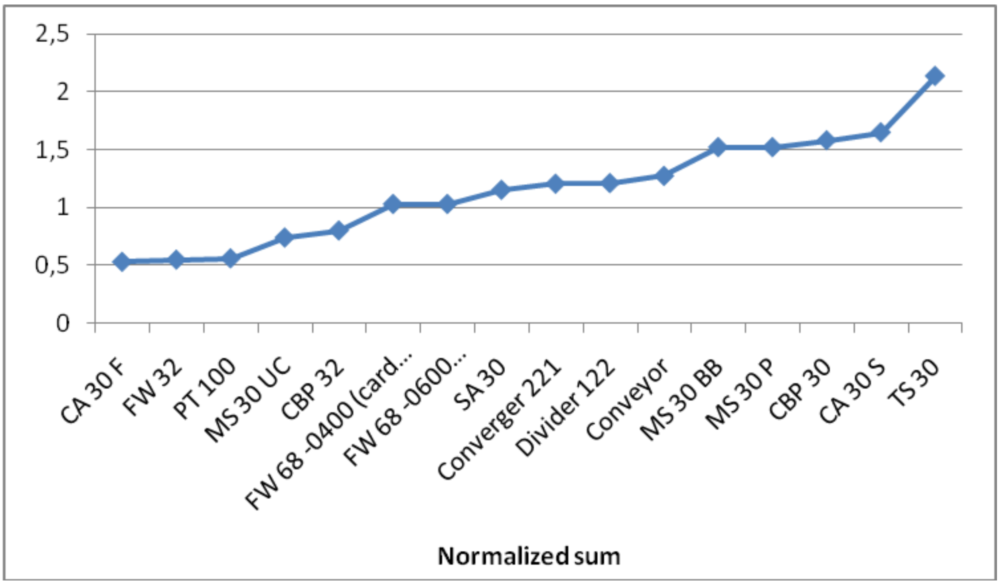


Figure 31. The significant attributes p*ackage volume*, *minimum capacity* and *frequency* combined to a ***normalized sum index***.

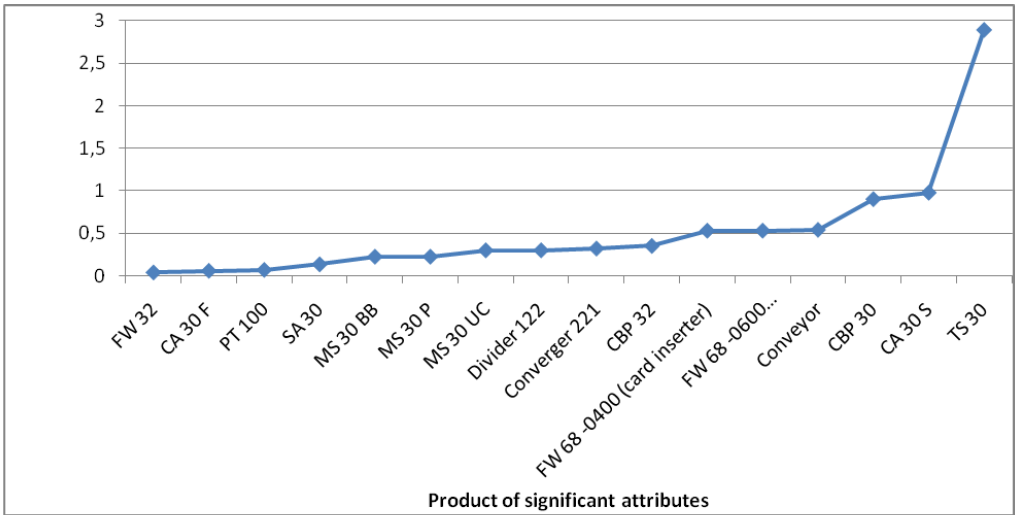
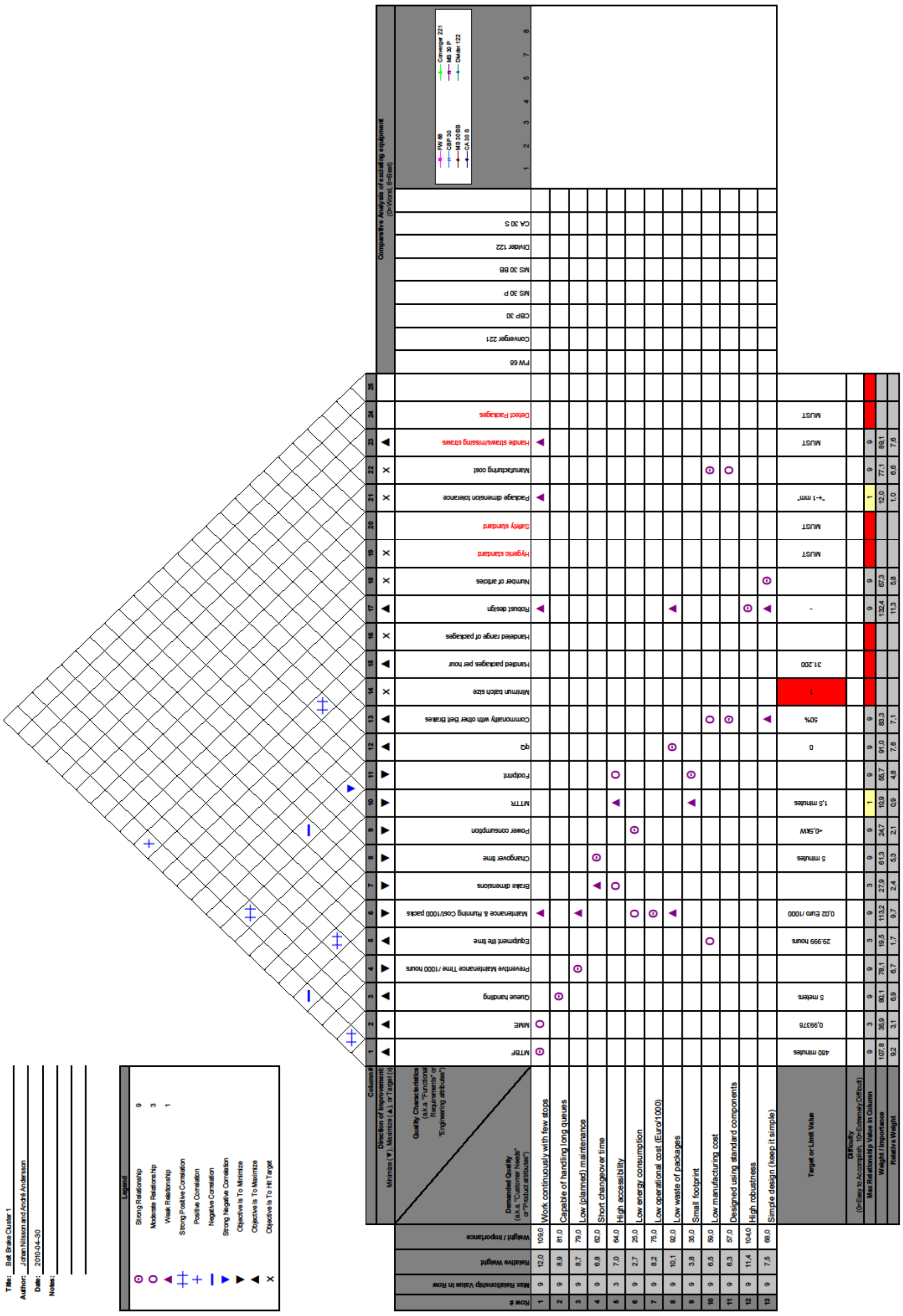


Figure 32. The significant attributes p*ackage volume*, *minimum capacity* and *frequency* combined to a ***product index***.

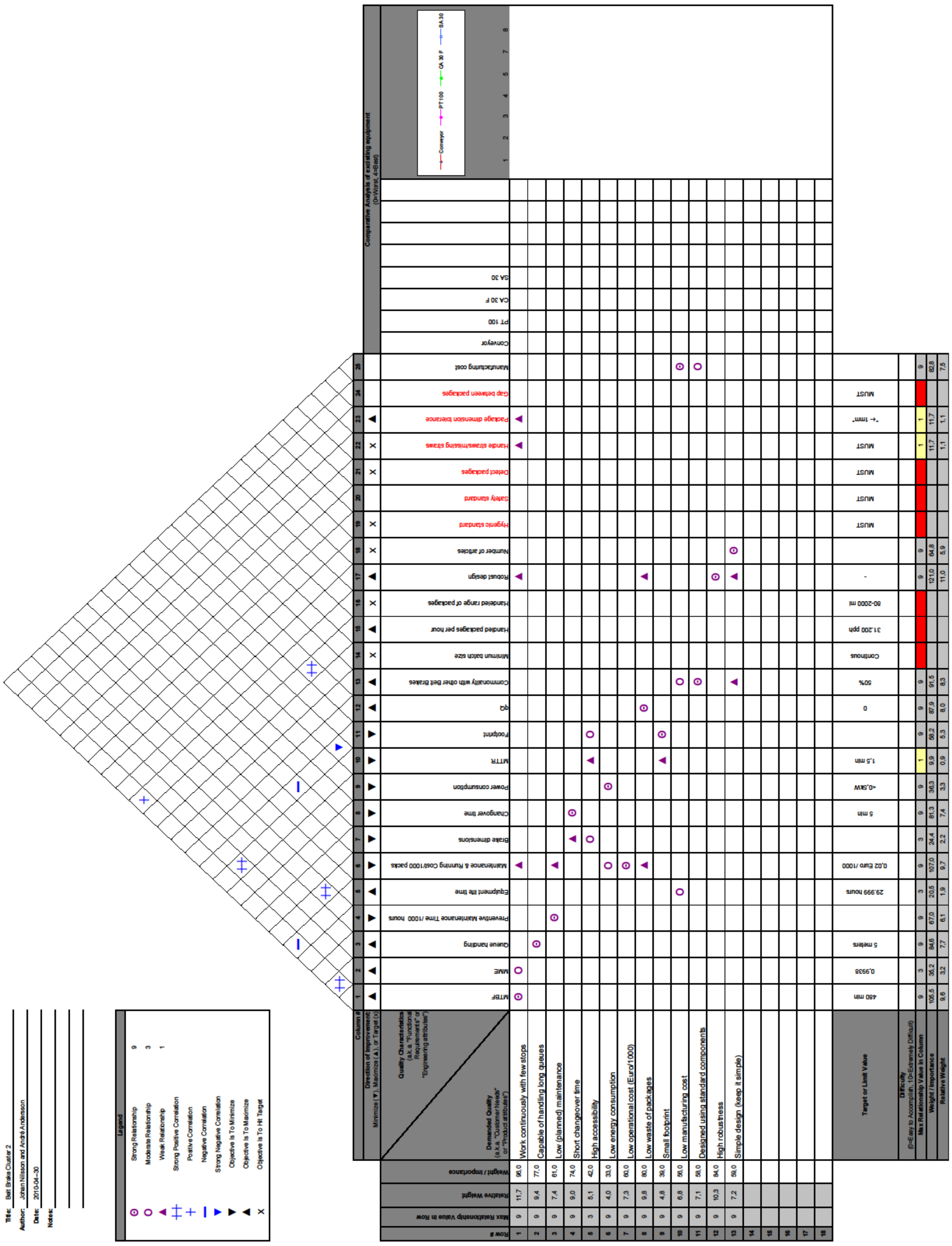
Appendix H – Results of House of Quality 1(3)

Cluster 1



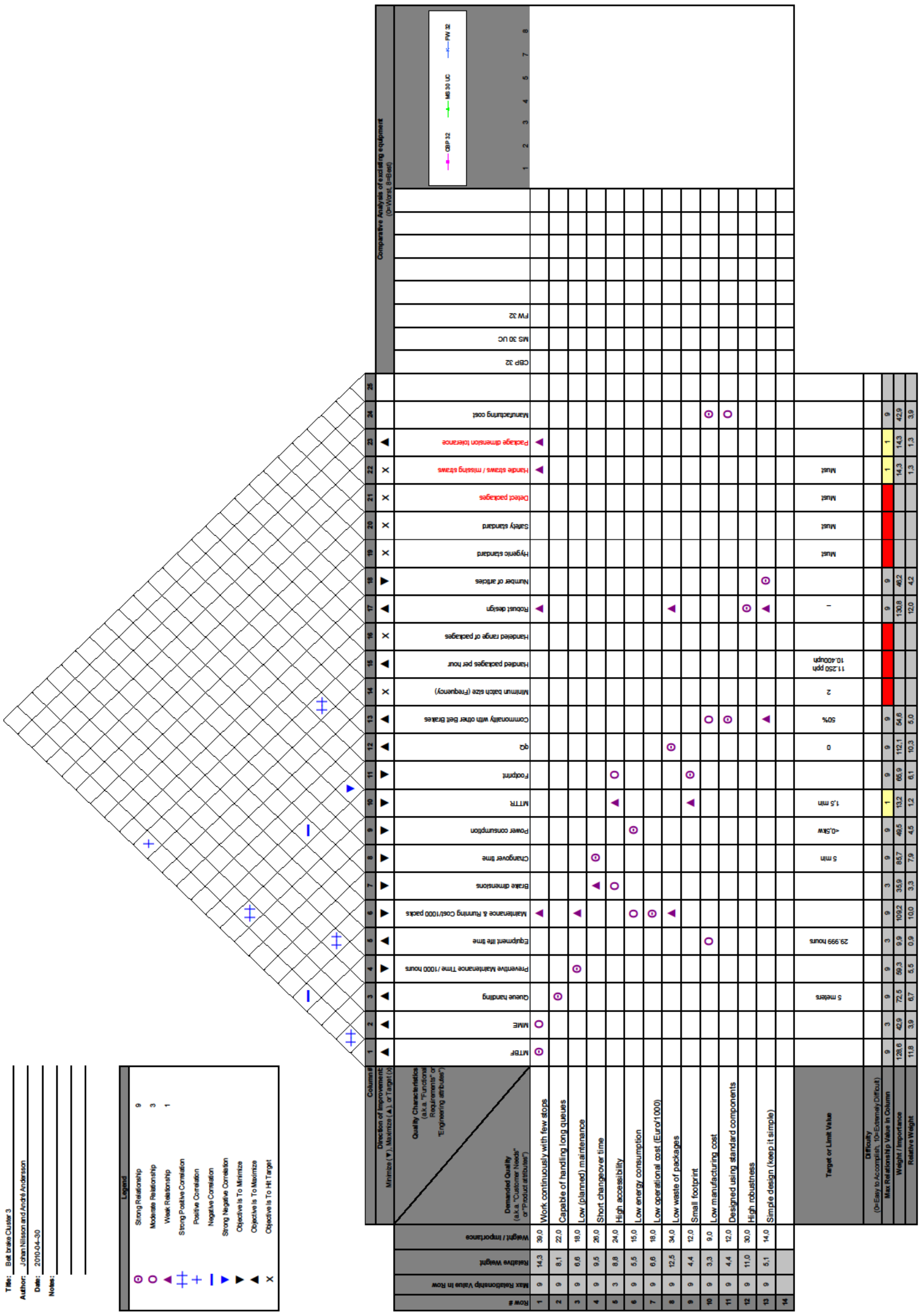
Appendix H – Results of House of Quality 2(3)

Cluster 2



Appendix H – Results of House of Quality 3(3)

Cluster 3



Appendix I - Applied engineering attributes

MTBF[59]

The *Mean Time Between Failures* indicates the reliability of the machine as it represents the mean time that elapses between the failures of the machine.

$$MTBF = \frac{\text{Operating time}}{\text{Numbers of stops}}$$

Operating time indicates the active production time.

MTTR [60]

The *Mean Time To Repair* represents the average time required to repair a failed element or device. Alternative meanings of the R could be restore, restart or recover.

$$MTTR = \frac{\text{Total reparation time}}{\text{Numbers of reparations}}$$

MME[61]

Machine Mechanical Efficiency is a measure on the availability of the machine. MWT (mean waiting time) is the time it takes from a stop occurs until the resource to solve the problem is put in. MWT is sometimes included in the MTTR measure; in that case the MWT is not visible in the denominator.

$$MME = \frac{MTBF}{MTBF + MTTR + MWT}$$

[59] Ståhl J.E., (2009), *Industriella Tillverkningssystem del II, p.72*

[60] Ibid

[61] Ibid p.75

Preventive Maintenance Time /1000 Production hours [62]
This attribute is defined as the labour necessary to perform Preventive Maintenance tasks within 1000 production hours, expressed in Hours/1000 Production Hours.

Equipment lifetime[63]
Equipment lifetime is the estimated lifetime for the equipment as per section *, expressed in hours.

* The life time of 29 999 hours must be used for all equipment in this calculation.

Customer Maintenance & Running Cost/Unit [64]
The Customer Maintenance & Running Cost/Unit is calculated according to the formula below.

$$\text{Maintenance \& Running Cost/1000 Packages} = \frac{\text{Spare Part Cost} + \text{Tetra Pak Service Work Cost} + \text{Customer Service Work Cost} + \text{Operator Cost} + \text{Consumables \& Utilities Cost} + \text{Material Waste Cost}}{\text{Total number of approved packages}} * 1000$$

Footprint
Footprint indicates the floor surface occupied by the fully installed machine.

Brake dimensions
To get the full specification of the element dimension only height has to be added to the footprint.

Queue handling
A brakes ability to absorb the force from the queuing packages, measured in meters of queue.

Changeover time
Changeover time is the time it takes the operator to adjust a machine when changing from handling one type of package to another.

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[62] Tetra Pak Internal, *Technical-standards*, 100506
[63] Ibid
[64] Ibid

Number of articles

Number of articles is the total number of articles that the machine is built up from.

Package dimensions tolerance

Package dimensions tolerance is the dimension tolerance a package might have without affecting the performance of the machine.

Manufacturing cost

Manufacturing cost is referred to as the cost Tetra Pak have to pay to produce a machine or when acquire a machine from a supplier.

Power consumption

The mean consumption of electrical power

qQ[65]

The product efficiency value for a packing machine corresponds to the waste share. This parameter can be represented as:

$$PE = \frac{\text{Number of approved packages out}}{\text{Number of approved packages in} + \text{Number of wasted packages}}$$

Number of wasted packages: Number of wasted packages due to the machine failure. Not external impacts as; mishandling from the operator, bad packaging material, bad applied straws, lack of power etcetera.

Commonality with other belt brakes

The Commonality with other belt brakes could be measured in numerous ways. In this thesis commonality calculations are represented by percentage of common parts.

[65] Ståhl J.E., (2009), *Industriella Tillverkningssystem del II, p.72*

Minimum batch size (frequency)
Is the number of packages that passes through a belt brake between two stop. It is related to the attribute frequency which represents the numbers of stop per second a brake can perform.

Handled packages per hour
This attribute describes the top capacity for the brake.

Range of handled packages
Range of handled packages describes which types of packages that can be handled by the belt brake.

Robust design
A robust product can be defined as a product that perform as intended under non-ideal conditions such as manufacturing process variations or a range of operating situations. The uncontrolled variations that may affect the performance are called noise. A quality product should be robust to this kind of noises. The product development activity of improving the desired performance of the product while minimising the effects of noise, is called robust design.

Hygienic standards
Hygienic design is an essential part of Food Safety and there are policies and standards developed to support the development of a product assuring a product will meet the requirements for hygienic design. The requirements can vary for different markets, it is therefore vital to know the different requirements of where the product will be launched before designing a product.

Safety standards
It is of importance that the safety aspects are considered. As with hygienic standards, safety standards also vary between different markets. There are many standards and legislations to comply with. To be able to do this in an efficient way Tetra Pak the company developed their own corporate standards. These standards will ensure compliance with the legal and quality standards that customers expect from Tetra Pak.

Appendix J –Proposed process