Evaluation of the Corrugated Box Strength Performance in Supply Chains

- A case study of Duni AB

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MASTER THESIS

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Abstract

Duni has successfully expand their business internationally. Internationalization makes the distance between the producer and consumers become longer and this leads to strength reduction of corrugated boxes along the supply chain. To overcome this problem, this study is conducted to find the extent of corrugated boxes strength reduction during logistical activities, practices and condition in the supply chain.

Three Duni products were selected for this project. Via interviews and on-site visits, supply chain mapping for each product was presented to assist in visualization. Relevant findings during observations such as unrealistic pallet configurations, inappropriate basic conditions and poor corrugated box design were highlighted.

Data loggers were utilized to measure shock, vibration, relative humidity and temperature while GPS trackers were brought in to detect the journey of the product. Shock readings were frequently detected during loading and unloading process at the supply chain actors with the maximum shock reading of >16.4g. Interestingly, transportation by road does not give a high shock reading. The average relative humidity of <50% was measured in Europe particularly during the project timeline can be considered as good.

By comparing BCT results, it is clearly shown that the strength of the corrugated box reduced as the packaging goes further along the supply chain flow. Primary packaging or products that corrugated box contained might help in giving the corrugated box a better support towards given compression. Self-open perforations and dented vertical edge that lead to strength reduction of the corrugated box were also observed. In the end, a decision tree is provided in order to help Duni in revising the safety factor of their corrugated box, hence improve its performance.

Keywords: corrugated box, strength reduction, safety factor, box compression test, shocks, relative humidity

Executive Summary

Introduction

Duni produces about 70% of their goods at their own manufacturing establishments across Europe. About 30% of the goods are sourced from all over the world, mostly from their Asian and European suppliers. Longer distances between the producer and consumers leads to strength reduction of Duni corrugated boxes along the supply chain.

Purpose & Goal

Purpose: To understand the interconnection between logistic condition, practices and activities that can eventually reduce the strength of the corrugated box.

Goal: To propose to Duni on how the safety factors of their corrugated box can be further revised and improved.

Methodology

Type of measurement	***Description***
Literature reviews	Familiarization with the topic and problem.
Interviews	Conducted individually and in a group to get a clearer picture of the problem with packaging strength
Observations	Participant (on-site visit) and non-participant observation to observe in real life, the current situation, practices and activities conducted at each actor across the supply chain
Data Logger	To measure shock, vibration, relative humidity (RH) and temperature (T) introduced to the packaging system
Global Positioning System (GPS) tracker	To detect the location of the packaging
Box Compression Test (BCT)	To see how much strength of the corrugated box would be reduced across the supply chain.

Overview

Three products were selected to represent Duni manufacturing facilities in Poznan and Bramsche and their supplier A in Shenzhen, China. The packaging system of the selected products were studied in details and supply chain mappings were provided for better visualization.

Product	*Origin*	*Description*
Product A	Poznan	Napkins 3-ply 33cm 20 pieces
Product B	Bramsche	Napkins 2-ply 40cm 125 pieces
Product C	Shenzhen	Stirrer box 112mm white

Data logger I is placed inside the secondary packaging of product A and B. Both products were transported or transferred from their manufacturing establishments to International Distribution Centre (IDC) in Bramsche. Data logger II is placed inside the packaging of product C. Product C was transported as loose load inside a cargo vessel from Shenzhen, China to Lohne Transport Logistik (LTL) in Germany for palletizing. As all products were meant for United Kingdom (UK) customers, they were undergoing re-palletizing process to change the load carrier from Euro pallet (1200 x 800 mm) to UK pallet (1200mm x 1000m). After that, all products with data loggers I and II inside their packaging were transported to Hellmann Logistics warehouses (transhipment point) in Osnabrück, Germany, in Litchfield, UK and in Colne Brook, UK. Smithers Pira in Leatherhead acted as the customer in simulation for this project.

Results & Discussion

A. Relevant finding during observation

Finding	*Observation*
Pallet pattern/configurations	• Mistake during manual stacking – boxes were not in the centre of the pallet, misalignment, gap between boxes. • Wrong pallet scheme with unrealistic box arrangement was issued
Basic condition in supply chain	• “Container rain” was observed inside the container from China • Triple and quadruple pallets stacking observed at LTL
Design of the secondary packaging	• Corrugated boxes with dented vertical edge due to excessive space or setting of the stretch wrapping machine

B. Shock/Vibration

i. Both manual handling and automated system able to cause great amount of shocks or vibrations to the boxes.
ii. Transportation by truck, on the road, gave the least shock or vibration impact compared to other logistics activities.
iii. Overall, most of the shocks and vibrations recorded during loading and unloading activities of the pallets across the actors in the supply chain.
iv. The corrugated box located at the bottom layer of the pallet always exposed to higher shocks or vibrations impact compared to other layers.

C. Relative Humidity (RH) and Temperature (T)

By benchmarking ISO standard test atmosphere for testing of pulp, paper and board which is 50% RH, 23 °C, average relative humidity of <50% was measured in Europe particularly during the project timeline can be considered as good.

D. Box Compression Test (BCT)

Type of measurement	***Description***
Unused corrugated box	Demonstrated the initial strength value possess by the corrugated box before it is being used
Unfilled corrugated box	Conducted by removing out the product from the box, thus the box will be emptied
Filled corrugated box	Conducted to see the contribution of the product or primary packaging inside the corrugated box in supporting the box towards given compression

i. Strength of the corrugated box reduced as the packaging goes further along the supply chain flow.
ii. Filled box of product A does not help in improving the corrugated box resistant towards the compression – excessive box space.
iii. Products or primary packaging (filled box) of product B & C give a good support to the corrugated boxes from the given compression.

E. Recommendations to revise the safety factor (SF)
Decision tree was provided, emphasized on:
i. If the content of the corrugated box (primary packaging or products) helps in providing mechanical support to the corrugated box from the given compression, hence, the corrugated box is well designed and can have minimum SF of 3 for newly produced corrugated box.
ii. If the filled corrugated box performed poorly than unused corrugated box or there is problem such as self open perforation, the corrugated box needs to be re-design.

Conclusion & Future Research

To achieve appropriate safety factor for corrugated box, Duni could follow the recommended decision tree that derived from the thorough data collections of shocks and vibrations, relative humidity and Box Compression Test (BCT) in the supply chain.

Future studies can be focused in three aspects:

i. Studies to see the interconnection and interaction of product, primary packaging and secondary packaging along the supply chain, in order to improve the design and functionality of each entity.
ii. Study on the possibilities in minimizing supply chain actors, thus promoting leaner supply chain – too many loading and unloading process
iii. Study on the ageing effects of the corrugated box by conducting a project that following an actual lead time of the products. To make it more interesting, the study can be conducted outside Europe, in a different continent and with various mode of transportation.

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Lund, June 2017

Muhamad Syahir Suhaimi

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1 Introduction

This section presents the background of the studies and highlighting the problem description. The purpose and goal of this master thesis are discussed in this chapter as well.

1.1 Background

1.1.1 **Background of Duni**

As a supplier of GoodFoodMood, Duni thrives to become the best player in the market by providing high quality table setting concept and accessories that help restaurants, caterers and take-away businesses creating a good atmosphere for their customer. With business to business as its foundation, Duni allows their customer to customized a product according to their particular needs. These customized items are usually sold under their customer's "private label". Hence, it is important for Duni to meet strict demands and achieve high customer satisfaction.

Duni produces most of their goods at their own manufacturing establishment. About 30% of the goods are sourced from external suppliers. These traded goods are coming from all over the world, mostly from their Asian and European suppliers. These traded goods are expected to have the same quality as their own produced goods. Packaging development division under the value chain department takes the main responsibility in ensuring a good quality packages are being delivered to their customer.

In today's supply chain environment, a company will have more expectation from their suppliers, same goes to Duni. To fulfil the expectation draws by a business, suppliers are now working closely with businesses and deliver what they want. Packaging plays an important role for the efficient supply chain (Dominic & Olsmats, 2001) hence Duni is now focusing on the improvement of their packaging system especially on the potential strength reduction of their package.

1.1.2 **Packaging**

Packaging is a crucial element for international and domestic trade. Without a packaging, product handling will be inefficient and impractical. Packaging also plays an important role in ensuring success in business, as a packaging can play a role as "silent" salesperson, acts as a communicating tool and conveying a company's product impression with a consumer. Packaging is there to provides information about the products and promote it through colour, design and size of it.

Robertson (1990) listed down 6 primary functions of packaging which are containment, protection, apportionment, unitization, convenience and communication. These packaging functions not only give impact on the product design, manufacturing, transportation, distribution, warehousing and marketing tools, but also are important in giving the company a competitive advantage.

Few types of secondary packaging such as FEFCO 0201, shelf ready packaging and transport packaging are used by Duni. All of the packages stated earlier made from corrugated cardboard box. In Duni, shelf ready packaging should reflect the premium product it contains and communicate the brand image to the customer. Duni has private label companies as their customer, and these private label companies are expecting not only a good quality product but also a good quality display packaging.

1.2 Problem Description

Internationalization makes the distances between the producer and consumers become longer, hence contribute to a growing need for a useful and competitive packaging systems (Dominic & Olsmats, 2001). Duni is facing the same problems at the moment especially with their traded goods that are coming from their suppliers in China. The main issue is regarding the strength reduction of the corrugated cardboard box. This reduction of strength lead to several problems such as stackability issue and dented box. The long distance journey of the traded goods from their supplier in Shenzhen, China to Duni International Distribution Centre (IDC) in Bramsche, Germany makes it hard to identify the real root cause of this strength reduction problem. This performance issue is also occurring at their European chain, involving the strength reduction of corrugated box for Duni own produced goods and traded goods.

From a collaboration with packaging institute, Duni has established a safety factor standard for different types of packaging, based on the distances – from Europe or Asia and based on the palletisation status – under hang or overhang pallet. However, with the current problem faced by Duni involving the strength reduction of their corrugated box, Duni wishes to investigate deeper on the actual root cause of this problem. Hence, Duni would want to understand how shock, vibration, relative humidity, handling of the package, or any other factors across their supply chain that can reduce the strength of corrugated boxes. With this finding, Duni is open on the possibility in revising the current safety factor possessed by their corrugated box.

Figure 1. Damaged secondary packaging in Duni due to strength reduction issue

1.3 Purpose and Goal

The purpose of this thesis is to understand the interconnection between logistic condition, practices and activities that can eventually reduce the strength of the corrugated box. While the goal of this thesis is to propose to Duni on how the safety factor of their corrugated box can be further revised and improved.

As highlighted by Åslund (2014), to be able to predict the performance of corrugated cardboard box, it is very important to understand its deformation and failure mechanism. Hence the following questions were derived for this study:

1. At which point across the supply chain can potentially contributed the most shock and vibration to the corrugated box?
2. What is the current relative humidity experienced by the corrugated box across the supply chain?
3. How can other factors such as packaging handling or pallet configuration reduce the corrugated box strength?
4. From the findings of this study, how can it help in revising the safety factor possess by the corrugated box?

1.4 Delimitation

The first delimitation for this project would be the inflexible timeline of this master thesis. This project was planned properly by researcher and Duni personnel in order for it to be completed within 20 weeks. Because of this, the actual lead time of the product from production until receiving by end consumer cannot be demonstrated in this project. Hence, ageing effects of the corrugated box were not taken into account.

The next limitation is the device competency used in this project. Since this project was the first packaging logistics project conducted by Duni, Duni or its supplier does not have an expert in this area. When two units of data loggers MSR 165 were sent to Supplier A in Shenzhen, China, researcher had provided them with easy-to-understand instruction on how to operate the logger as shown in Appendix A. The setting for the loggers were set in advance by researcher, thus Supplier A only need to install and turn on the logger. However, due to mishandling and miscommunication at their side, both loggers were not turned on. Hence, 7 weeks of shock, vibration, relative humidity and temperature data introduced to the corrugated box from China to Germany were not recorded. Nevertheless, researcher still have sufficient data from European chain to meet the purpose and goal of this project.

The broad geographical coverage in this project can also can be considered as a delimitation. This is because, researcher was unable to visit Supplier A in China or any supply chain actors in the United Kingdom. The loggers should be able to operate and record the data properly if researcher personally went to China and to handle the installation and activations of the data loggers. In UK, observation was done by third person, a Duni representative. Because of that, the interpretation sometimes was different than expected. Two persons can have similar goal but not necessarily sharing the same perspective in achieving the goal.

Last but not least is the confidentiality of some information inside this project. The identity and activities of the supplier and customer cannot be exposed too much. Hence, some restriction in details of describing them occurred in this master thesis. Same goes to the BCT and safety factor data. Only necessary values will be shared inside this master thesis. But the BCT and safety factor values shared in this thesis is enough to meet the purposes and achieving the goal.

2 Methodology

In this chapter, methods of carrying out the project are highlighted. Different type of interviews, ways of observation and specification of devices are discussed.

2.1 Overall Approach

Figure 2 demonstrates the overall approach/ method design for this project. After the purpose and goal have been established, research questions were derived from it. By maintaining the concept of system thinking in mind, literature reviews (secondary research) were done for familiarization with the topic and problem. Next, to investigate the strength reduction of corrugated box, primary research was done through interviews, observations, collecting data from loggers, Box Compression Test (BCT) and Global Positioning System (GPS) tracker. After data collections were completed, the raw data was analysed and interpreted. Finally, the findings are reported and presented in this master thesis. The details of each steps will be explained throughout this chapter.

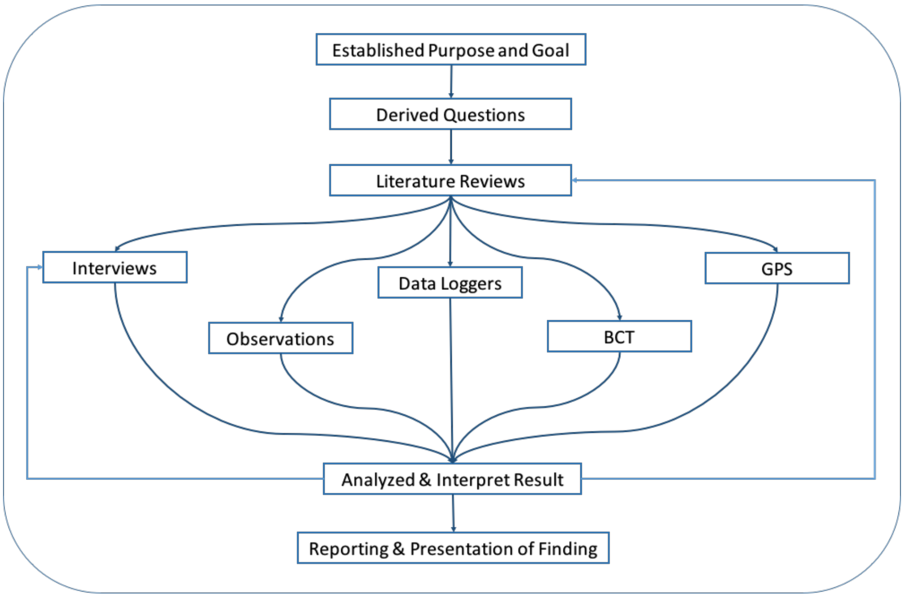

Figure 2. Overall methodology approach

2.2 Literature Reviews

To have a better understanding and ground knowledge of the research topic, literature research was conducted by referring to reading materials related to the corrugated box issues. The early target of this literature research was to give an idea to the researcher on the main contributor to the strength reduction problem of corrugated box. On top of this, early literature reviews were also giving researcher some ideas on the appropriate research methods to use, experimental design to conduct and what kind of interview and observation should be done.

Lund University database and Google search engine were used to find useful and informative articles. The Lund University's library resources also provided a source of useful information for references. After the data gathering and analysing, more literature reviews that cover the technical topics related to corrugated box and its strength such as Box Compression Test (BCT), safety factor, impact of different mode of transportation, relative humidity, loading/unloading pattern, pallet configurations, overhang, packaging material, and storage duration were conducted in order to give better explanation and support the results obtained.

2.3 Interviews

Interviewing is an extremely flexible research tool (Breakwell, 1995) that can be used in any stage of a research process. During initial phase, interviews were conducted with Duni employees in order to get a clearer picture of the packaging strength problem. A meeting was then conducted between the researcher, Lund University supervisor and Duni employees at Duni headquarters in Malmö, Sweden. From this meeting, a thesis proposal was generated.

The interview continues during the sourcing process of a suitable data logger and GPS tracker for this project. Few suppliers such as Intab and Kvalitest Nordic were approached in order to obtain data logger specifications that meet all requirements needed. The logger must be able to record shock, vibrations, relative humidity and temperature. While for GPS tracker, suppliers such as Minifinder and Nordtrack were approached in order to get small and powerful GPS that can be installed inside the packaging, yet still able to transmit the satellite signal.

Interviews are open to any biases and shortcomings (Brewerton & Millward, 2001), hence in order to achieve reliable and valid results, the interviews were conducted with objectification limited to packaging and its interaction only. The product performance was not taking into account. Moreover, interviewees were asked to quantify their answer as much as possible.

Interviews were conducted individually and in a group. Section 2.3.1 and 2.3.2 will discuss more about this. Interviews were performed face to face, through email communication, tele-conversation or by the help of third-person from Duni as an interviewer. The list of respondents that participate in the interview sessions were listed in Table 1 and Table 2.

Table 1. Interview respondents from Duni

Respondent	***Location***	***Date of Interview***	***Designation***
Wilbert Baerwaldt	Malmö, Sweden	11th January 2017	Value Chain Director
Johan Ericsson	Malmö, Sweden	3rd February 2017	Senior Sourcing Manager
Reine Alm	Malmö, Sweden	16th January 2017	Packaging Development Manager
Izabela Wloszczynska	Poznan, Poland	15th March 2017	Phase In/Out Manager
Magda Czyzewska	Poznan, Poland	15th March 2017	Logistic Manager
Pawel Majewski	Poznan, Poland	15th March 2017	Implementation Engineer
Malwina Binkowska	Poznan, Poland	15th March 2017	Product Technology Specialist
Thomas Determann	Bramsche, Germany	24th March 2017	Logistics Inbound Manager
Hans-Joachim Stahmeyer	Bramsche, Germany	24th March 2017	Quality & Environment Affairs Manager
Hendrik Budke	Bramsche, Germany	24th March 2017	Engineering Manager
Matthias Kramm	Bramsche, Germany	24th March 2017	Project & Process Engineer
Manuel Botte	Bramsche, Germany	24th March 2017	Project & Process Engineer
Olena Gärtner	Bramsche, Germany	25th March 2017	Quality Lab Assistant

Table 2. External interview respondents

Respondent	***Company/Location***	***Date of Interview***	***Designation***
Håkan Jonasson	Intab Interface	7th February 2017	Technical Engineer
Lauri Selänne	Kvalitest Nordic	8th February 2017	Product Manager
Marco Kukuruzovik	Minifinder	13th February 2017	IT Consultant
N/A	Nordtrack	14th February 2017	Customer Service
Alice Yip	Supplier A, Shenzhen, China	28th February 2017	Project Liaison
Stefan Behring	Lohne Transport Logistik (LTL), Germany	22nd March 2017	Account Manager for Duni

Marc Jarman	Hellmann Logistics	25th May 2017	European Branch Manager
Paul Cyples	Hellmann Logistics	25th May 2017	European Road Freight Warehouse Controller
James White	Smithers Pira	27th April 2017	Project Manager
Ben Harrop	Smithers Pira	27th April 2017	Project Manager

2.3.1 **Individual interviews**

The respondents of the interview were well aware that the questions will be asked are related to the corrugated box strength issue. But in order to allow the question to evolve during the interview process, most of individual interviews were done in unstructured ways. This method was perceived as the most suitable way. Breakwell (1995) highlighted that the depth of exploration in unstructured interviews may well be of the same level as the structured interview, since both are dependent on the knowledge and skills of the interviewer. Hence, unstructured interviews should not be viewed as less effective in comparison to structured interviews.

As stated earlier, individual unstructured interviews were conducted at early phases of this project, where Duni employees were interviewed in order to have better understanding of the problem and the supplier of the devices were also interviewed in order to get the correct data logger and GPS for this project. Individual interviews were also conducted before on site visit and throughout the visit (details about visit in section 2.4.1). This ad hoc interviews throughout the visit was to equipped researcher with the essential knowledge – to have better understanding on the process or the particular situation.

Interview process with Alice Yip from Supplier A in China (Table 2) was done individually through email communication. This is due to distance and time difference between Sweden and China. Alice Yip act as Supplier A liaison for this project. Structured questions were provided to her, so that she can discuss and answer the questions with her team in China. Individual interview sessions in Hellmann Logistics and Smithers Pira in United Kingdom (Table 2) were conducted by Reine Alm, Duni Packaging Development Manager using structured questionnaire prepared by the researcher.

2.3.2 **Group interviews**

Group interviews and discussions were done in Poznan and Bramsche during the last day of on-site visit. The participations of the group interviews mostly came from respondents in table 1 with 4-5 people in each location. Each group session took about 1 hour and 30 minutes. The main purpose of these group interviews were to aligned the answers given by every participant that involved during the visit. Structured questionnaire that inspired by Dominic & Olsmat (2001) (Appendix B) was sent earlier to all of the participants so that they can prepare themselves with an answer for every questions. Plus, additional to the structured questionnaire that was sent out earlier, new questions that were developed throughout the visit, were asked during the group discussion. Voice recording took place throughout the discussion for future reference.

The participants from different background such as engineering, logistics and quality assurance were gathered during the discussion. Not only to make sure that everyone is aligned, but also this group discussion has given them an exposure on the journey of the packaging from production until it arrives to the distribution centre/warehouse. It can be seen that some of Duni employees were not fully aware of the task of other departments. Hence, this is an opportunity for them to understand the process as a whole, with holistic views, and indirectly improved their knowledge. Moreover, with this group discussion, everyone had an opportunity to share their thought and opinions, therefore a lot of new ideas generated.

2.4 Observations

The aim of observation is to observe in real life, the current situation, practices and activities conducted at each actor across the supply chain. It is impossible to observed everything that happen to each packaging system in Duni. Hence, for this thesis, the sampling size has been narrowed down to three Duni products. The description about these three products were discussed in section 4.1, page 20.

In order to make sure the reliability and validity of the observation, every observation was not conducted alone and always with someone else that is responsible for the area observed. Pictures and video recordings were taken for future references. From this observation, the effectiveness of the interaction between logistic activities and the packaging system were evaluated and subsequent questions were developed by looking at the current situation.

2.4.1 **Participant observation – on site visits**

According to Brewerton & Millward (2001), with participant observation, the researcher immerses himself with the situation and target to observe the actual happening personally. Hence, in order to get a better understanding of what is happening throughout the supply chain, on site visits were arranged by Duni for the researcher.

Before visiting Duni establishment in Poznan, Poland and Bramsche, Germany, several discussions were conducted in between researcher and Duni personnel in

Malmö, Sweden and both locations. These discussions were needed to align the goal of each visit and ensuring that the visit will be a fruitful one. Researcher expectations were highlighted clearly to the team in Poznan and Bramsche through email communication and tele-conversation so that everything needed for this project can be prepared in advance.

Researcher spend four days in Poznan, visited Duni manufacturing, conducted project briefing, observations, interviews, shock/vibration test, relative humidity test and etc. Working trip to Bramsche took 5 days where researcher had an opportunity to visit Duni manufacturing, Duni International Distribution Centre (IDC) and visited four Lohne Transport Logistik (LTL) warehouses that stored Duni product in several locations in Germany. Throughout the visit, same activities were done as in Poznan, with a lot of pictures and videos recording, plus Box Compression Test (BCT) was performed in Bramsche.

2.4.2 **Non-participant observation**

In non-participant observation, the observations were not done on-site but by pictures and video recordings. Due to time and budget restriction, researcher was unable to visit all of the actors that involved in the supply chain process. Because of that, information, pictures and videos of supply chain activities were given by Alice Yip from Supplier A and Reine Alm, that visited different supply chain actors in United Kingdom.

2.5 Data loggers

According to Trost & Alfthan (2016), shock and vibrations during transport and handling are a problem to corrugated box performance. They also mentioned that, the higher the humidity introduced to the corrugated box, the poorer the performance of the corrugated box becomes. Hence, in this master thesis, shock, vibration, relative humidity (RH) and temperature (T) that were introduced to the packaging system had been measured by using data logger.

Through interviews and online research, researcher had suggested Duni to purchase data logger MSR 165 (Figure 3). According to MSR 165 datasheet, shock monitoring is possible up to ±15g. For this project, it is observed that the shock reading can still be recorded until 16.4g. With integrated 3-axis digital accelerometer, this logger was also able to record the vibrations that happen following every shock. Working range for relative humidity is from 0 to 100% and for temperature, it is from -20°C to 65°C. MSR 165 is widely known and used by companies and institution that usually conducted transportation test (MSR 165 Data Logger for shock and vibration, 2017), hence the data produced were reliable.

Figure 3. Data logger MSR 165

As shows in Figure 4, the logger was installed inside the packaging. This installation started at production line where the packing process took place. Hence shock that introduced to the package at packing machine, conveyor and etc. were measured. Then, these loggers travelled together with the product to measure shock, vibration, RH and T across the supply chain.

Figure 4. Installation of data logger inside the package

The data logger was installed inside the packaging by researcher at Poznan manufacturing, Bramsche manufacturing and Duni International Distribution Centre (IDC) in Bramcshe. For Supplier A in Shenzhen, China, the data loggers were sent by air freight to the project liaison, Alice Yip and she had installed the data logger inside the packaging.

The minimum limit to trigger the shocks/vibration reading was set at 3g. This 3g value was determined after the discussion with the logger supplier, Intab. The recording duration for RH and T were set differently between logger A and logger B. Logger A used for European chain was set to record the data with an intervals of 15 minutes, while logger B used by Supplier A in Shenzhen was set to record with intervals every 30 minutes. These different settings were made after considering the travel distances and memory space of the loggers.

Åslund (2014) highlighted that the bottom box is subjected to highest compressive loads and the first to fail. While Gardner & Cooper (2003) said that vibration cause the top pallet to bounce on the bottom pallet. Hence to check this theory, two data loggers were placed for the journey between Duni International Distribution Centre (IDC) – Hellman Logistics – Smithers Pira, UK. Two data loggers were also installed for loose load cargo transportation from Supplier A in Shenzen, China to Lohne Transport Logistik (LTL) in Bramsche. Figure 5 demonstrates the location of these loggers.

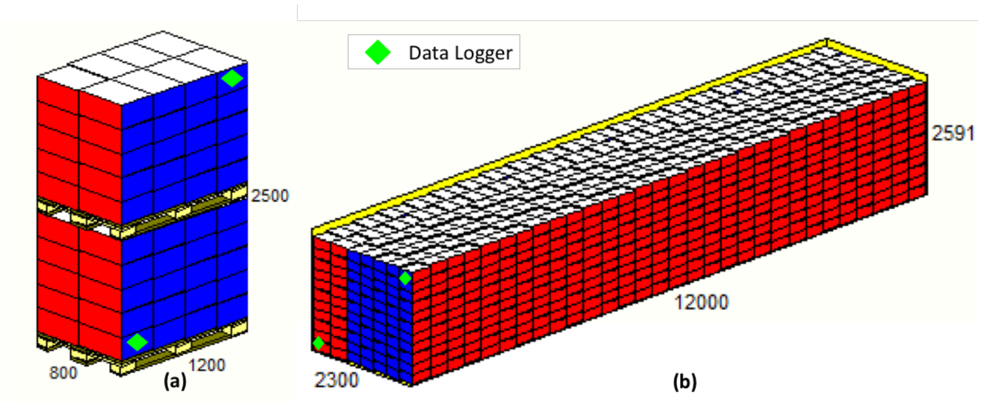

Figure 5. Shows how the data loggers were placed. (a) was the locations of loggers on pallet during transportation from IDC to UK while (b) was the locations of loggers inside the cargo container during transportation from Supplier A in Shenzhen, China to LTL warehouse in Bramsche, Germany.

2.6 GPS tracker

Figure 6 shows the Global Positioning System (GPS) tracker, name Xtreme GM7 by Minifinder that was brought in for this project. The reason to use GPS devices is to detect the location and route taken by the truck, cargo vessel or any other mode of transportation. It was easy to point out roughly at which location the shock/vibrations were introduced to the packaging. The RH and T data spikes recorded by the logger is also highly influenced by the location of the packaging. Similarly, like data logger, GPS trackers were placed inside the packaging. The placement of the GPS tracker was near to the container ceiling and door, so that the satellite transmission will not be disturbed. Tracktor software was installed to the computer in order to give live update of the location.

Figure 6. GPS tracker Xtreme GM7

2.7 Box Compression Test (BCT)

BCT (Figure 7) was conducted to see how much strength of the corrugated box would be reduced across the supply chain. This reduction is linked back to the factors that might contribute to it. BCT is performed at 2 different locations which are at Bramsche manufacturing and Smithers Pira in UK. Duni has one BCT machine and it is located in Bramsche manufacturing. Hence, BCT that was conducted in Bramche manufacturing was to reflect the reduction of strength that happen to the packaging that travelled from other Duni manufacturing in Europe or Asian supplier to IDC in Bramsche. While BCT in Smithers Pira reflecting the reduction of corrugated box strength when it travels from IDC to the customers in United Kingdom.

The BCT was conducted using ISO standard method, with laboratory climate of 23°C and 50% RH. Testing of BCT was performed on single boxes. The test method was top to bottom loading, between two steel plates. Corrugated box was placed in between these two steel pallet.

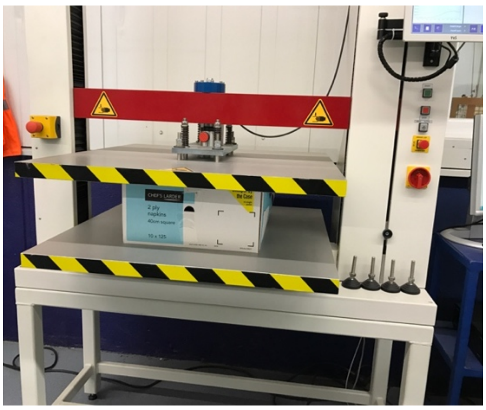

Figure 7. Frank PTI Box Compression Test machine in Bramsche manufacturing

3 Frame of Reference

This master thesis is grounded on some concept, theories and finding from previous studies or research. This chapter will guide the reader to go through the relevant reference thus give a clear idea on the direction of this project.

In order to understand the interconnection between logistic condition, practices and activities that can eventually reduce the strength of the corrugated box, four topics were discussed under the frame of reference. Packaging logistics knowledge is important to understand the interaction between packaging system and logistic activities. Supply chain mapping will help to visualize the current supply chain flow of Duni, hence it is easier to identified a problem.

Knowledge on corrugated box is also very important in order to determine the performance of corrugated box in different situation and environment. Last but not least, knowledge in safety factor can lead to better understanding on how safety factor works. With this understanding, a suggestion can be given to Duni on how to review the current standard of safety factor that they have.

3.1 Packaging Logistics

Dominic et al. (2000) define packaging logistics as an approach which aims at developing packages and packaging system in order to support the logistical process and to meet customer or user demands. Since this project is heavily based on the supply chain and logistical process of packaging, good understanding of the packaging logistics concept is vital.

According to Saghir (2004), packaging has significant impact on the efficient and effectiveness of retail supply chain. In order to enable improvement, models are needed to facilitate evaluations along the supply chain and show the activities involved in the supply chain. Hence supply chain mapping was conducted in this project and explained in the chapter 3.2.

This project was conducted with a system thinking concept and as highlighted by Hellström & Saghir (2006), by looking at system perspective, there are three areas of packaging that can be improved which are the logistics process, packaging system and the interaction between the two. Different packaging level and different packaging process should be investigated simultaneously for improvement.

When talking about packaging logistics, other factors such as marketing and environment that directly impact the packaging system should also have been taken into account (Jahre & Hatteland, 2004). Figure 8 adapted from Johansson, Lorentzon, Olsmats, & Tiliander (1997), highlighted the connection between packaging system, logistics, marketing and environmental factor.

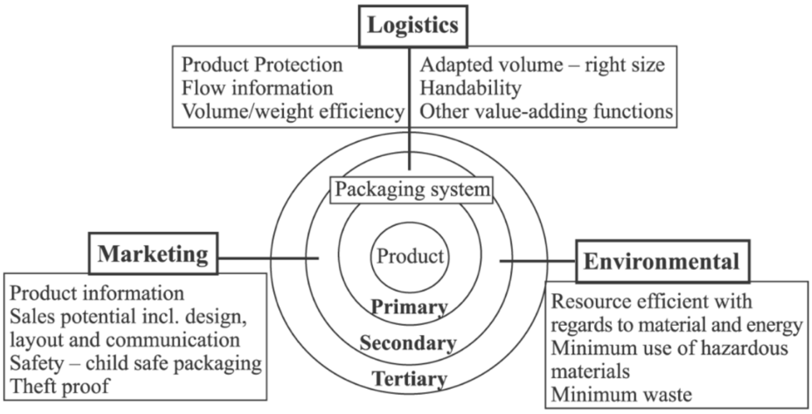

Figure 8. Connection between packaging system and logistics, marketing and environment

3.2 Supply Chain Mapping

According to Christopher (2016), supply chain is a network of connected and interdependent organizations mutually and co-operatively working together to control, manage and improve the flow of materials and information from supplier to end users. As the company expanding globally, it is harder to visualize, managing and tracking the supply chain (Gardner & Cooper, 2003). Hence, supply chain mapping is needed in this project for better visualization of the supply chain flow and logistical activities.

According to Justensen (2012), a supply chain mapping is a visual representation of goods, information, processes and money flows that occur throughout a supply chain, both upstream and downstream. A supply chain mapping can also be called as process map or flowchart. Process map is used to increase understanding about a process, helping in generation of ideas, improved communication between different actors that engaged in the same process and last but not least, to document the process (Anderson, 2017). Often times a process map will identify bottlenecks, repetition delays, or gaps. Furthermore, process maps can also help to clarify process boundaries, process ownership, process responsibilities and effectiveness measures (What is Process Mapping, 2017).

Logistics costs varies by company and industry. It can be estimated around 10% per products (Christopher, 2016). Because of this, continues improvement efforts such as lean supply chain and elimination of waste are taken place. Today's supply chain is mostly focusing on the integration between the companies towards the customer and suppliers (Myerson, 2015). That can be seen by Duni efforts in connecting with their suppliers and improve customer satisfaction with this project.

3.3 Corrugated Box

3.3.1 **Brief description**

Performance of corrugated boxes is the centre of this study. Hence it is important to know the details of it. Corrugated boxes have all positive features for transporting and storage (Åslund, 2014). It can protect the products from dirt, shock, vibration and humidity (Trost & Alfthan, 2016). It can also be used as a communication tool, maintaining the integrity of a product with its strong durable characteristic (Nordstrand, 2003). In year 2015, the global packaging market had an estimated value of $839 billion, with paper and board materials take 31.11% of material in values, the highest among others (all4pack, 2016).

Because of its lightweight characteristic and the ability to be recycled, corrugated box is considered as cost effective and environmentally friendly material (Nordstrand, 2003). However, current trend in packaging industry shows that the industry's increasing demand for cheaper alternatives, hence, the amount of materials used to make corrugated box were also reduced. According to report by FEFCO (2013), the grammage of corrugated board has been reduced and the proportion of recycled fibres is also quite high in corrugated board.

3.3.2 **Problem faced**

Globally, the main problem faced by companies in regards to the corrugated box would be the lack of uniformed performance standards and guidelines that are available for generalist and specialist. This might happen due to the varying performance of corrugated cardboard, depending on which part of the world it is bought. They might have similar nominal quality but the performance varies locally. Hence, industry might find it difficult to establish a global standard for corrugated cardboard box performance (Trost & Alfthan, 2016).

The weakness of the corrugated box would be moisture exposure and the ability to absorb water. This can reduce the strength and stiffness of the corrugated board. However, this can be overcome by making it both water and grease proof (Nordstrand, 2003). The strength of the corrugated box varies significantly depending on the age (Trost & Alfthan, 2016).

Corrugated box commonly suffer from core structure damage during manufacturing, converting and printing process. During this process, pressures are applied and it can cause thickness reductions up to 20%. Thus, this reduce the mechanical performance of cardboard box (Chalmers, 2007). Shock and vibrations during transport and handling are also a problem for corrugated box (Trost & Alfthan, 2016).

Variation in logistic activities and climate is hard to be tackled in any other ways than through the use of safety factor. However, lacking of test method for performance during distribution leading to the use of large safety factors and this safety factors are used in many different ways, which create uncertainty (Trost & Alfthan, 2016).

3.3.3 **Specification**

The most common form of corrugated board is single-wall corrugated board. This single-wall consists of two face sheets, called liners that are bonded to the wave shaped web called fluting or medium. This is shows in Figure 9. The fluting pipes that oriented in the cross-direction (y, CD) making the corrugated board to be extremely stiff in bending and stables against buckling in relation to its weight. The orientation of the board in alignment to the production is called machine direction (x, MD). Whereas, the orientation for the thickness of the board is represented with Z-direction (z, ZD) (Nordstrand, 2003).

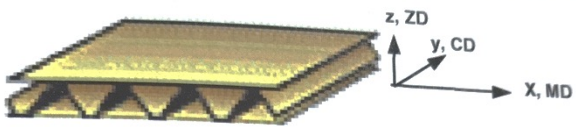

Figure 9. Single-wall corrugated cardboard box

Single, double or triple-wall board are formed by a series of corrugator machine in line as shows in Figure 10 (Nordstrand, 2003). About 80% of production of corrugated board in the industry is in a single-wall condition. Double or triple-wall corrugated board are needed for special needs packaging solution (Nordstrand, 2003). The most valuable method on box level to calculate the box strength is BCT. (Trost & Alfthan, 2016)

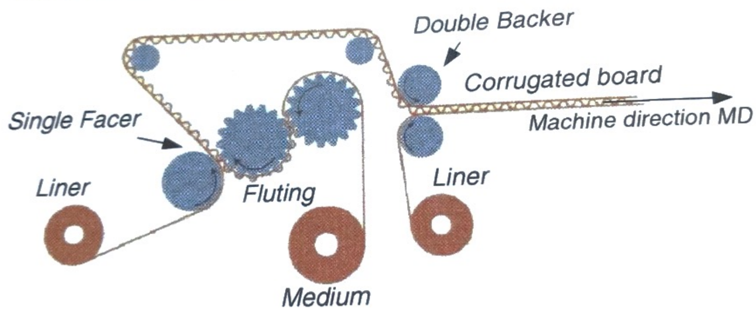

Figure 10. Manufacture of corrugated cardboard box

Different fluting design is for different purpose. It is depending on the wavelength, λ (mm) and height, h_c (mm) of the flute. From table 3, B and C-flute are most common corrugated board grades that are used in the industry. A-flute comes with highest wavelength and tallest height is considered as a heavy duty corrugated box and designed to transport heavy product. While E-flute and F-flute are small and used for smaller box where the printability, artworks and appearance is very important (Steadman, 2002).

Table 3. Flute Profiles (Åslund, 2014)

Profile	*A*	*B*	*C*	*E*	*F*
Wavelength, λ (mm)	8.3-10	6.1-6.9	7.1-8.3	3.2-3.6	2.3-2.5
Flute height, h_c (mm)	4.0-4.8	2.3-3.0	3.2-3.9	1.0-1.8	0.7-0.8

FEFCO (European Federation of Corrugated Board Manufacturers) code is an international standard that are widely used in designing corrugated box. The most common box is the regular standard container (RSC). RSC is specified with its length (L) x width (W) x Height (H). With an in-line Slotter-Folder-Gluer (one operation to creases, cuts, folds and glues the blank for its final shape), RSC is delivered flat to the customer. In Sweden, a transport package is usually adjusted to the size of the Euro-pallet (1200x800 mm). This RSC is usually come in the size of 300x200 mm or 600x400mm.

3.4 Safety Factor

In order to give a suggestion to Duni on how their current safety factor can be revised, it is important to have a basic understanding of it. In theory, the safety factor is an estimation that, based on the various conditions the container will be subjected to, including its design, tells the designer how much stronger to design a container than the actual weight on the bottom container in a load (Corrugated Compression Strength, 2014).

HP Compression Test Method (1996) states that the strength characteristics of corrugated box cannot be predicted within its normal range of use. Factors such as humidity and temperature changes affect corrugated greatly. Other than that, shocks, vibration, compression, and printing can reduce the strength of flute structure. Carrying capacity of corrugated box can reduce up to 50% due to misalignment of vertical edges from one box on top of another

Distribution activities can alter the strength of a corrugated box drastically (HP Compression Test Method, 1996). Meaning, the more severe the shipping and distribution environment, the higher a safety factor is required. A safety factor is used as a multiplier in the calculation to makeup what the elements of the distribution environment take away (HP Compression Test Method, 1996).

If the corrugated box need to be four times stronger than the greatest weight it will have to support, this means the initial compression strength of the container should be four times the most weight it will ever have to support. This container will carry a safety factor of four (Corrugated Compression Strength, 2017).

It's a mix perspective from everyone in the industry on how much the safety factor should be, but a rule of thumb in the corrugated industry is between 3 and 5. This means for a corrugated container, it should be designed to be 3 to 5 times stronger upon initial testing that the greatest load it will have to support (Corrugated Compression Strength, 2017).

4 Empirical Descriptions

This chapter provides knowledge derived from investigation, interviews and observations throughout the project. Process flow of the products are also discussed in this chapter.

4.1 Overview of studies

This master thesis study has a broad coverage of topics under it. Hence this overview section will give a better understanding, on how this study was conducted. The details of each topic were discussed in the next part. It is impossible to cover all Duni products and packaging design in this master thesis. Hence, three products were selected to represent Duni manufacturing facilities in Poznan and Bramsche and their supplier A in Shenzhen, China. The chosen products were Duni high runner product for United Kingdom customer. The packaging system of the selected products were studied in details. Table 4 shows the list of selected products.

Table 4. Products selected for this studies

Product	***Description***
Product A	Napkins 3-ply 33cm 20 pieces
Product B	Napkins 2-ply 40cm 125 pieces
Product C	Stirrer box 112mm white

Figure 11 displays the overview of this master thesis. Own Produced Goods Process covers the flows of both products A and B produced in Poznan and Bramsche. Data logger I was placed inside the secondary packaging of product A in Poznan manufacturing. Product A was then transported to International Distribution Centre (IDC) in Bramsche. Once it arrived in IDC, data logger I is removed out from product A and transferred to the secondary packaging of product B. Product B was packed in the Bramsche manufacturing's production area and sent to IDC. When product B arrived at IDC, data logger I is not removed out from product B, instead it remains inside the secondary packaging of product B.

Traded Goods Process is destined for supplier A based in Shenzhen, China. Data logger II is placed inside the packaging of product C. Product C was transported as loose load inside a cargo vessel. Next, container arrived at Lohne Transport Logistik

(LTL) in Germany for palletizing. After palletizing, product C was sent to IDC. Data logger II remains inside the packaging of product C. In IDC, Box Compression Test (BCT) was conducted towards the secondary packaging of Product A, B and C.

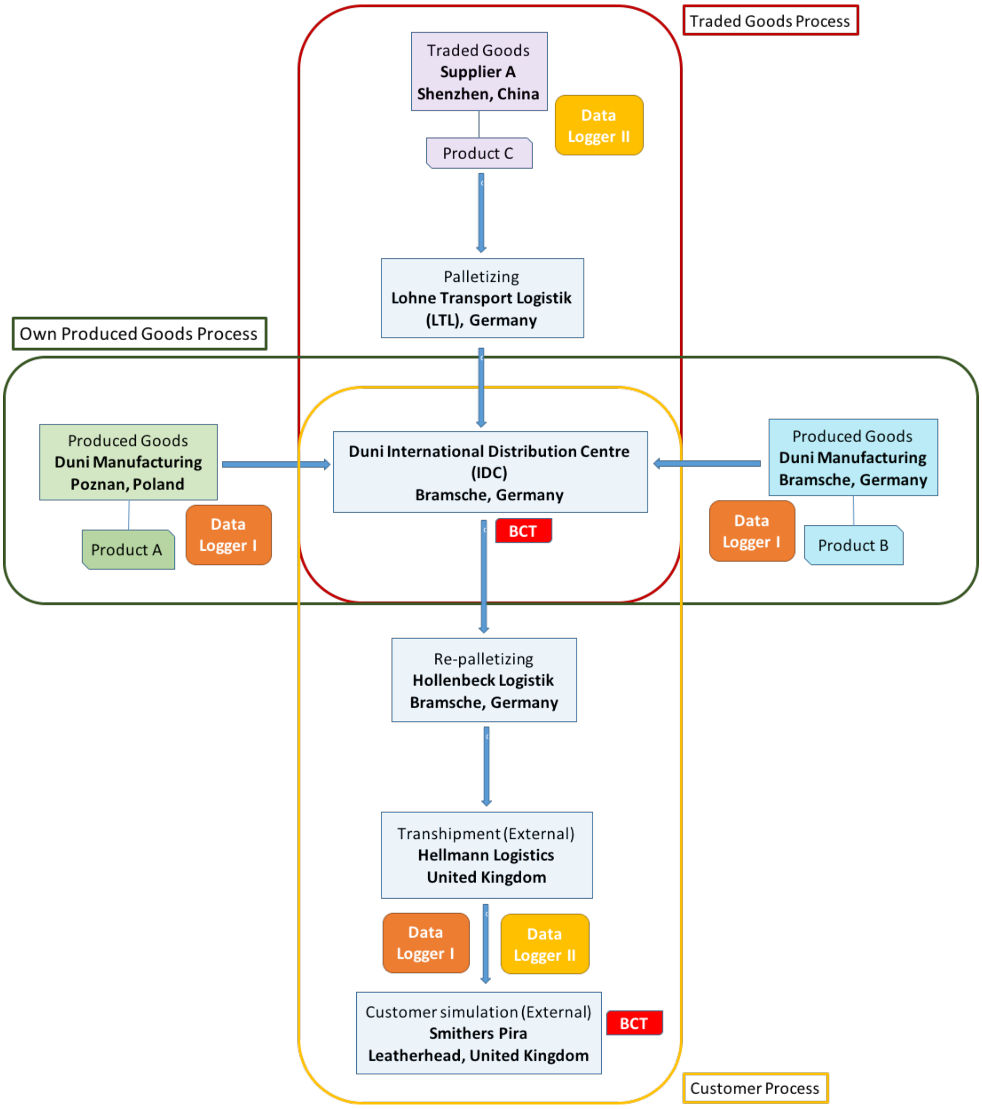

Figure 11. Overview on the scope covers by this master thesis

This project requires product A, B and C to be sent to the UK customer (Customer Process). All products were undergoing re-palletizing at Hollenbeck Logistik in Bramsche, Germany. The purpose of the re-palletizing process is to change the load carrier from Euro pallet (1200 x 800 mm) to UK pallet (1200mm x 1000m). With these new UK pallets, product A, B and C were transported to Hellmann Logistics warehouses in Osnabrück, Germany, in Litchfield, United Kingdom and in Colne

Brook, United Kingdom. The data loggers I and II were transported together with the products. To simulate the supply chain activities that took place during the delivery process to customer in United Kingdom, Smithers Pira was selected. Located in Leatherhead, Smithers Pira was also the place where second BCT was conducted.

4.2 Packaging Description and Process Mapping

Packaging descriptions and process mapping are important in order to understand the packaging levels of each product and the flow of process involved. At this section, only supply chain process that involve actors controlled by Duni will be discussed while for the third parties' actors in United Kingdom, the discussions are in section 4.3, page 29. But, even though Supplier A is not controlled by Duni, the manufacturing part of Supplier A in Shenzhen, China was discussed here as well. Figure 12 shows the scope of discussion for this section.

Figure 12. The scope of discussion for section 4.2 marked with red dot box

IDC establishment is owned by Duni while Hollenbeck Logistik warehouse in Bramsche is a rented warehouse by Duni. However, staffs working in Hollenbeck Logistik are under Duni's employment and Duni take control of all activities within the establishment. On the other hand, Hellman Logistics is an external warehouse and Smithers Pira acted as a dummy customer, as a simulation for this project.

4.2.1 **Packaging originates from Poznan**

The supply chain flow demonstrated in Figure 13. Product A which is Napkins 3-ply 33cm 20 pieces per package was selected for this project. 20 napkins were packed automatically inside polypropylene (PP) plastic as a primary packaging

(Figure 14). This primary packs were then going through barcode machine where barcode stickers were placed at the back of the pack.

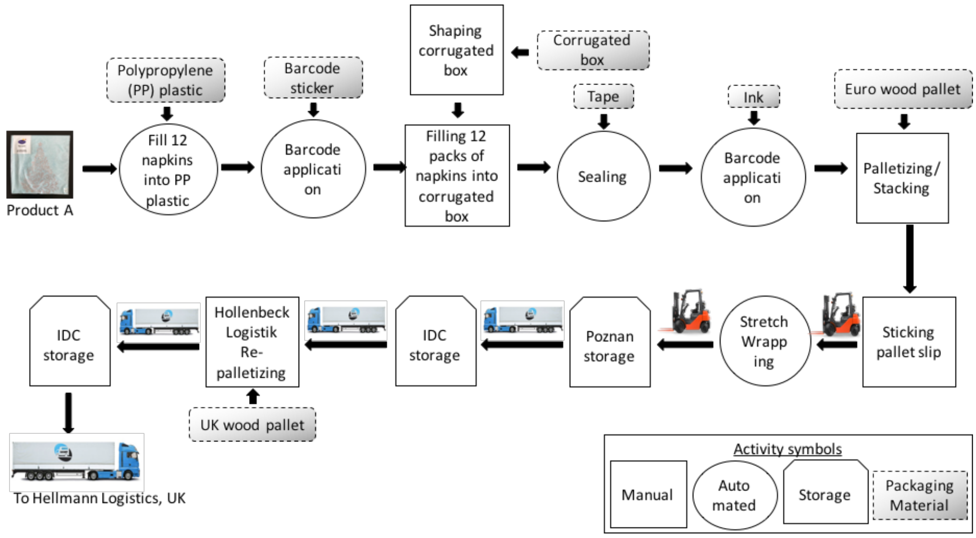

Figure 13. Process flow for packaging originates from Poznan

Figure 14. Napkins 3-ply 33cm 20 pieces packed inside polypropylene (PP) plastic

12 packs of 20 pieces' napkins were then transferred manually inside the secondary packaging – corrugated box, FEFCO 0201 (Figure 15). After gone through barcode machine that automatically printed the barcode at the side of the boxes, this corrugated boxes were then transferred manually by operator onto the pallet. The secondary packaging is consisted of brown box in colour (Figure 15), single-wall with C-flute. The external dimension of the box is 325mm x 174mm x 183mm with the theoretical BCT value of 1600N. After the napkins were manually packed inside the box, it went through case sealing machine where 50mm clear self-adhesive tape was placed at the top and bottom part of the corrugated cardboard box.

Figure 15. The secondary packaging on the conveyor after went through case sealing machine

The pallet is then transferred by forklift to a plastic stretch wrap machine inside the warehouse (Figure 16). After wrapping, product A is lined up at the warehouse area while waiting for the truck to be sent to Duni International Distribution Centre (IDC) in Bramsche, Germany.

Figure 16. The condition of tertiary packaging after gone trough plastic wrapping process

Product A is designated for the customer in United Kingdom (UK). Hence, from IDC, the pallets were sent to the Hollenbeck Logistic that located about 1.5km from IDC by truck. In Hollenbeck Logistik, re-palletizing activity took place where, the corrugated boxes were transferred manually from Euro size pallet to UK size pallet. Because of the re-palletizing activity, the quantity of the boxes/pallet were changed. Originally in Euro pallet, the quantity was 84 boxes/pallet while in UK pallet, 105 boxes can be fitted in one pallet, which is 21 boxes more in comparison to Euro pallet. After re-palletizing activity in Hollenbeck Logistik finished, the new UK size pallets were sent back to IDC for further transportation to United Kingdom.

4.2.2 **Packaging originates from Bramsche**

The supply chain flow for packaging originates from Bramsche is demonstrated in Figure 17. Product B which is Napkins 2-ply 40cm 125 pieces per package was selected for this project. Unlike product A which was manufactured in Poznan, product B undergoes a fully automated packaging filling process. 125 napkins were packed automatically inside polypropylene (PP) plastic as a primary packaging (Figure 18). Prior to the napkins being packed inside PP plastics, the plastic will undergo barcode printing process where ink was injected directly to the outer layer of the plastics.

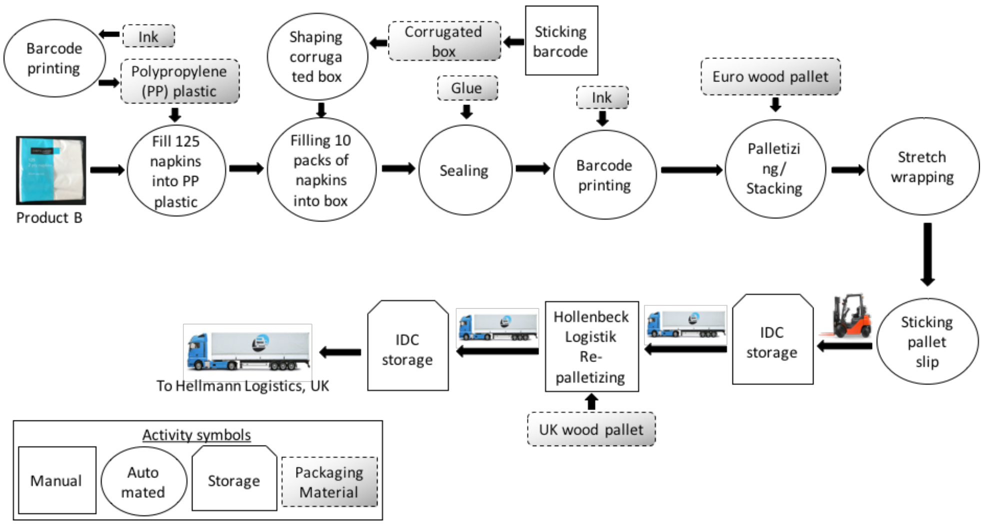

Figure 17. Process flow for packaging originates from Bramsche

Figure 18. Napkins 2-ply 40cm 125 pieces inside polypropylene (PP) plastic

10 packs of 125 pieces' napkins are then transferred automatically by filling machine to the secondary packaging – corrugated box, shelf ready packaging. The boxes are automatically formed by the machine as well. The secondary packaging consists of pre-printed shelf ready packaging, single-wall with C-flute. The external dimension of the box is 557mm x 413mm x 217mm with the theoretical BCT value

of 3000N. After the napkins are packed inside the box, it goes through gluing process where industrial glue is placed at the top and bottom part of the corrugated cardboard box. After that, the shelf ready packaging moved along the machine and the flaps of the box folded and sealed by machine.

Figure 19. Overhead ceiling conveyor system

Product B is then automatically lifted up via a product lift to an overhead ceiling conveyor system (Figure 19). Overhead ceiling conveyor plays a role in transporting the product from packing area to palletizing machine and then stretch wrap machine. The distance between the packing area and the palletizing machine was approximate 50m. After palletizing and wrapping – only the top part to provide stability, product B is transferred to Duni International Distribution Centre (IDC) by conveyor system (Figure 20). Bramsche manufacturing and IDC are wall to wall establishment. Forklift will then transfer the box to the storage area in IDC before product B is being transported to Hollenbeck Logistik for re-palletizing to UK size pallet. 25 boxes of product B were on UK size pallet instead of 20 boxes for Euro size pallet. Similar like product A, product B is designated for the customer in United Kingdom (UK).

Figure 20. Pallet was transferred from Bramsche manufacturing to IDC by conveyor

4.2.3 **Packaging originates from Supplier A, Shenzhen**

Product C's supply chain flow is demonstrated in Figure 21. Product C, a Stirrer box 112mm white 2000 pieces per package is selected for this project. 2000 stirrers were packed manually inside primary blue cardboard box with pre-printed barcode (Figure 22).

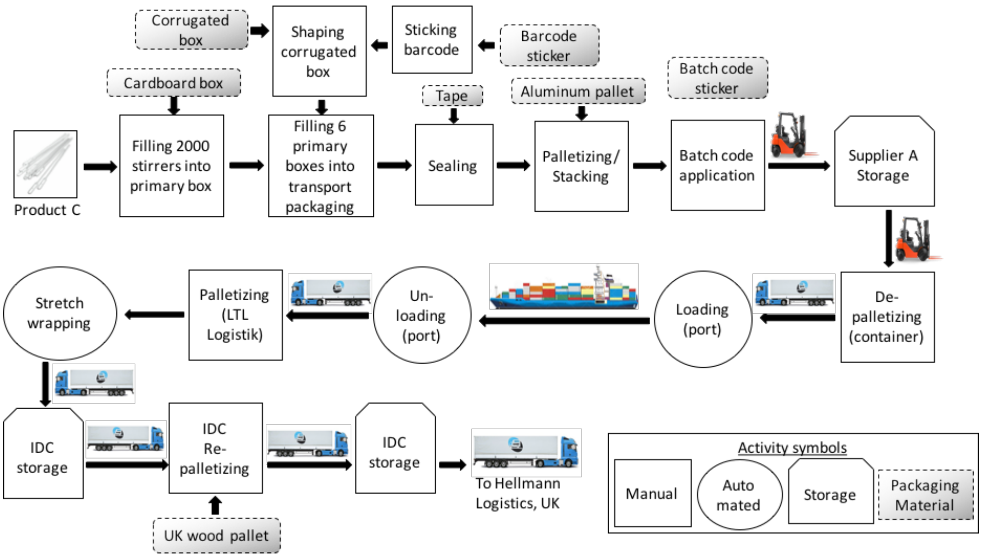

Figure 21. Process flow for packaging originates from Supplier A in Shenzhen, China

6 boxes of 2000 pieces' stirrers are then transferred manually inside a secondary packaging – corrugated box, in the form of transport box (Figure 23). 45mm clear self-adhesive tape were used to manually seal the corrugated box. The barcode stickers were placed at the side of the boxes. These corrugated boxes are then transferred manually by operator onto an aluminium pallet. The secondary packaging consists of brown box in colour, single-wall with C-flute and the external dimension of the box is 406mm x 207mm x 225mm.

Figure 22. Stirrers were packed manually inside primary cardboard box

Figure 23. Primary boxes were manually filled inside the corrugated box

The pallet is then transferred by forklift to the warehouse for temporary storage before uploaded to a container. When the container arrives, forklift transfers product C to the loading area and the boxes are manually loaded inside the container. Product C was transported as loose load inside the container (without pallet). Loose load of boxes inside the container is as demonstrated in Figure 24.

Figure 24. Loose load boxes arranged inside container

The container then travelled to the port near Shenzhen and uploaded to the vessel. This cargo vessel took 7 weeks of journey through open sea before arriving at Hamburg port in Germany. From the port, product C is transported to Lohne Transport Logistik (LTL) in Bramsche for palletizing, using Euro pallet. After palletizing, product C is transported by truck to IDC. Product C is designated for a customer in United Kingdom (UK). However, unlike product A and B, this product was re-palletize onto UK size pallet in IDC instead of Hollenbeck Logistik. The process ended when the product's pallets were transported out from IDC to United Kingdom.

4.3 Supply chain activities in United Kingdom

Referring to Figure 25, in this section, external supply chain actors involved in this project are discussed.

Figure 25. The scope of discussion for section 4.3 marked with red dot box

Hellmann Logistics in Osnabrück, Germany, in Lichfield, United Kingdom and in Colne Brook, United Kingdom functions as the transhipment hub for Duni product dedicated for United Kingdom. In Hellman Logistics, according to the customers' order, the original batch delivered from IDC are split into smaller size batches depending on the location of the order/customer. Next, another truck from Hellmann Logistics is used to transport out these new smaller batches to customers across United Kingdom. Hellmann Logistics in Leatherhead acts as a centre transhipment hub for UK while Hellmann Logistics in Colne Brook is responsible for the delivery at the southern part of United Kingdom. Smithers Pira in Leatherhead, United Kingdom is not a real customer and is used as customer simulation in this project. BCT is also conducted in Smithers Pira. BCT results will be discussed further in Section 5.4, page 48. Process flow for external supply chain actors is as per demonstrated in Figure 26.

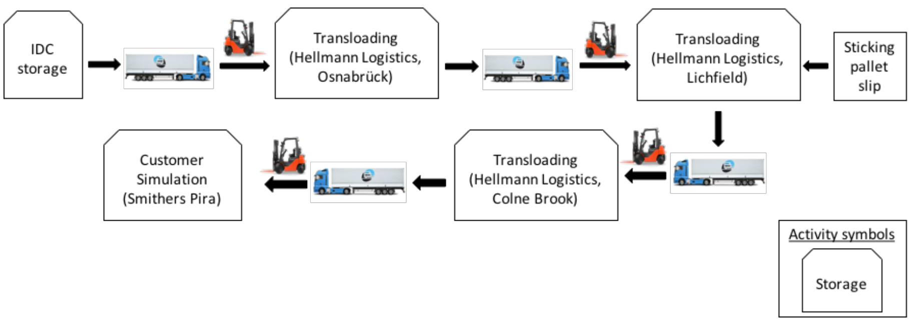

Figure 26. Process flow for packaging in external supply chain actors

5 Results & Discussion

This chapter provides the result and discussion derives from the data collected. The unit of analysis for this studies would be the corrugated box packaging strength.

5.1 Relevant Finding During Observation

In general, Duni has done a good job in their total operations especially on the condition of their manufacturing establishment. However, throughout the on-site visit to Poznan and Bramsche, researcher found some practises and activities in Duni that need urgent attention. These findings were considered as a gap in their packaging, logistic and supply chain system. This gaps can lead to reduction of corrugated box strength.

5.1.1 **Pallet pattern/configuration**

One of the biggest reasons in Duni that contributed to the reduction of corrugated box strength issue and lead to stackability problem would be their pallet configurations especially if the pallet has to go through the manual stacking process. Even though a correct pallet configuration was given to the operators, the individual skills varies quite a bit. The operator might follow the pallet configuration given, but they tend to make mistakes such as the boxes were not arranged properly in the centre, causing misalignment or too much gap between one box to another (Figure 27).

This practise should be improved as it affects the stacking properties of the boxes. When the stacking arrangement is not optimized, it will cause a problem especially when these pallets are double stacked. Weight from the top pallet is not evenly distributed to the bottom pallet hence the bottom pallet will loose its mechanical strength more easily. Moreover, this problem can lead to tilting or stackability issue of the pallets during long transportation.

Figure 27. Pallet configurations issue of product A after manual palletizing at Poznan Manufacturing

As shown in Figure 27, there were some numbers of pallets configuration issue at the Poznan Manufacturing from the beginning of this project. This affect the pallets' condition at the end destination which was at Smithers Pira. In Figure 28, interlayer movement of the boxes were observed and eventually lead to the overhang issue. This situation might also have contributed to stackabily problem.

Figure 28. The condition of product A with overhang pallet at Smithers Pira (customer simulations)

Next problem would be regarding wrong pallet scheme was designed and used by third party warehouse for traded goods product. This finding was observed at Lohne Transport Logistik (LTL) located in Germany during the palletizing process of traded goods that arrived from China in the form of loose load inside the container. The pallet scheme given to LTL came with an unrealistic pallet configuration as shown in Figure 29.

Figure 29. Pallet scheme for traded goods from China

The product in Figure 29 was not product C that was dedicated for this project. But this shows that the pallet scheme for traded goods were practiced without proper control within the organization. From the interview with LTL personnel, usually when LTL staff obtained the unrealistic pallet scheme, they will not follow the scheme and re-arranged the boxes themselves to assist in the stability of the pallet. This situation happens at least once per month. Correct pallet configuration not only provide stability and give the opportunity for the pallet to be stacked, but it is also important to ensure that the fill rate of the pallets is maximized.

Pallet scheme should be a control document. As Duni are using Cape pack software, this software should be used to create pallet scheme. Few departments can produce pallet scheme but every pallet scheme created should get an approval from one department that acts as a guardian. As highlighted by Sohrabpour & Hellström (2011), Cape pack is good software since it will consider the intended logistics and climate conditions and not only about the fill rate on the pallet. With simplified Mckee model for single or double wall board type, it can predict the stacking strength. Hence, more training might be needed for the target users of Cape pack. Super users of Cape pack can also be established in every factories or department that have the right to produce the pallet scheme. These super users will then transfer the knowledge within the department.

5.1.2 **Basic condition in supply chain**

There are few practice or situations in supply chain actors that need urgent attention in order to avoid more serious issues relating to product quality and packaging performance. The first problem is regarding the "container rain" observed on the container's ceiling. This observation took place at Lohne Transport Logistik (LTL) where the traded goods from China arrived in the form of loose load inside a container will be transferred to the pallets. Figure 30 depicts the situation of container rain. The distance between the most top corrugated box inside the container is about 15cm from the ceiling. As this water from the ceiling drop onto the corrugated box, it will soften the box, thus reducing its strength and its ability to be stacked.

This container rain is formed when warm temperature inside the container drops and become colder. Warm air can hold much more moisture compare to cold air, hence when temperature inside the container drops, the container become more humid and condensation takes place (Roche, 2013). In the container, a fast temperature change of 5°C or 10°C is enough to cause condensation (Inside a container, 2014). This container rain situation can also lead to cargo sweat situation if water appear at the inside part of stretch wrapped plastics. However, cargo sweat was not observed during the visit due to the products were transported in the form of loose load, without stretch film.

Figure 30. Container rain observed on container's ceiling

Next, the concern was on the triple and quadruple pallets stacking observed at LTL (Figure 31), and Hollenbeck Logistik (Figure 32). From the interview conducted with Reine Alm, he explained that the safety factor standard established in Duni was for double stacking and not for triple or quadruple stacking. Based on the literature research, the 3 to 5 safety factors recommended to the corrugated box industry was also taken into account for double stacking only. Since at the moment, Duni are still not implementing the safety factor standard of 4 throughout all corrugated box, this triple and quadruple might still not a big issue. However, if Duni decides to use the standard safety factor that they have in the future, triple and quadruple stacking are not suitable for this. Duni might need to re-organize their warehousing system so that this staking problem can be overcome. Åslund (2014), stated that due to top to bottom compression, it is obvious that the bottom stack will be first to fail when subjected to highest compressive loads.

Figure 31. Quadruple stacking at LTL

Figure 32. Triple stacking at Hollenbeck Logistik

5.1.3 Design of the secondary packaging

Molina-Besch & Pålsson (2014) said that it is difficult to get a good balance between product protection, marketing, logistics and environmental requirements in designing a packaging. Hence a problem like head space and improper usage of pallet space can occur. This shows that packaging development should in parallel with designing a product. This is to ensure that not only packaging meet all the requirement in operations, supply chain, business and also guarantee product integrity

Corrugated box for product A shows a major problem at the vertical edge of the box that come contact with the stretch film (Figure 33), irregardless which layer that the boxes were located. When too much pressure introduced to the corrugated box and it becomes dented, corrugated boxes, loses some of its mechanical properties. This dented vertical edge problem was not only observed at product A, but throughout the visits to Duni warehouses, this problem can easily be observed at other packaging (Figure 34). This problem might occur due to two reasons. The 1st reason could be because of the setting at the stretch wrap machine was set too high that caused the stretch wrapping machine to wrap the product too tight and cause dented vertical edge.

Figure 33. Picture taken at Smithers Pira, dented vertical edge observed at product A.

Figure 34. Picture taken at LTL, dented vertical edge observed almost at every side

However, considering that is the function of stretch film, to hold the product together, to protect and provide stability, maybe the stretch film setting was within the specification. 2nd reason might be due to the excessive free space inside the packaging. Corrugated box that used to contain 12 packs of napkins for product A can actually used to contain up to 15 packed of napkins with similar specification as well. Hence, it is obvious that since this corrugated box for product A only contains 12 packs of napkins instead of 15, there were high amount of unused spaces inside the box. Moreover, from the observation done by researcher, it is observed that the corrugated box for product A had a certain amount of headspace as well. Hence, the corrugated box for product A was transporting not only the product but also a lot of air. When it is wrapped with stretch plastic, too much space within the box might contributed to dented vertical edges. Nevertheless, the quality and the machine setting of stretch wrap plastic is still a concern due to tear off plastic wrapped was observed at few actors in UK, as shows in Figure 35.

Figure 35. Tear off plastic wrap observed in Smithers Pira

5.2 Shock/Vibration

This section will discuss in detail the activities throughout the supply chain that contributed to the shock/vibration readings. GPS tracker, pictures and videos recorded throughout the visit were used to identify the incidents by matching it with the timing of the incident. However, some of the data cannot be interpreted accurately due to shocks/vibrations that occur when researcher was not on-site to record or the GPS tracker was unable to get satellite signals. Hence, for this unidentified part, the data were interpreted by looking at the most recent or later event that took place before or after the shock readings were recorded by the logger.

All of the data loggers were set with a same setting. The minimum limit to trigger the shocks reading was at 3g while the maximum value of shock introduced to packaging was unknown since the logger can only measure the maximum of 16.4g of shock. Even though shocks reading above 16.4g cannot be recorded, the results were good enough as indicator at which point or activities contributed to shock/vibration the most. With integrated 3-axis digital accelerometer, logger was able to record the vibrations that happen following every shock. Because of this, vibrations will not be discussed in details at this section as every shock that took place indicates the present of vibrations as well.

5.2.1 **Poznan Manufacturing to IDC, Bramsche**

In order to investigate the shock/vibrations generated by packing machine, conveyors and etc., the measurement start at the packing line (production area). Then, these loggers travelled together with the product to IDC and Hollenbeck Logistik to measure shock, vibration, RH and T across the actors involved. Figure 36 shows the shock results recorded by MSR 165. The early part of the graph with the marking of "Installation of Logger" is not taking into account since that was the noise given by the logger when it was placed inside the corrugated box packaging.

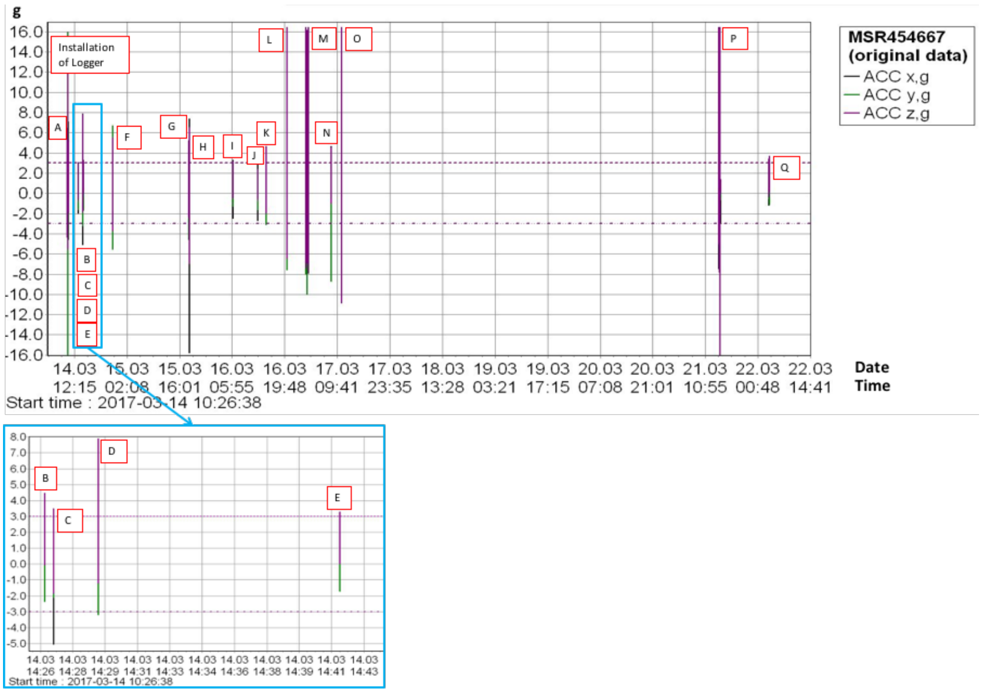

Figure 36. Data logger A shows shock/vibration results of product A that originally come from Poznan factory

The description of the shock details as below:

A: 5.8g, happened when the corrugated box was transferred manually from the conveyor (after packing) onto the pallet.

B: 4.5g, happened when the wrapped pallet was automatically transferred from the orange rotating conveyor to another roller conveyor at the stretch wrap machine area (figure 37).

Figure 37. Two conveyor connected, from rotating orange conveyor to roller conveyor

C: 3.5g, another shock took place at the roller conveyor at the shrink wrap machine area.

D: 7.9g, happened when pallet was placed on the ground by forklift after taken it out from stretch wrap machine.

E: 3.3g, unloading pallet from forklift to the warehouse area, lined up waiting for the truck.

F: 6.7g, pallet movement inside warehouse in Poznan.

G: 7.4g, movement of pallet before it is being loaded inside the truck for transportation to Bramsche.

H: 6.5g, loading/placement of pallet inside the truck.

I: 3.3g, during transportation. Road in Poland as shows in Figure 38.

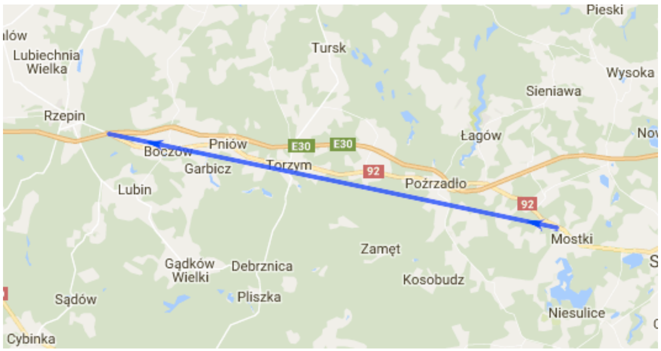

Figure 38. Area where shock recorded in Poznan

J: 3.1g, during transportation. Road in Germany, after passed Hanover as shows in Figure 39.

Figure 39. Area where shock recorded in Germany

K: 4.7g, unloading of pallet from the truck to IDC in Bramsche.

L: >16.4g, internal movement/transfer of pallet inside IDC.

M: 16.2g, loading/placement of pallet inside the truck. The pallet was transferred from IDC to Hollenbeck Logistik for re-palletizing.

N: 4.7g, internal movement/transfer of pallet in Hollenbeck.

O: >16.4g, manual re-palletizing process in Hollenbeck (Euro pallet to UK pallet).

P: >16.4g, internal movement/transfer of pallet in Hollenbeck.

Q: 3.7g, pallet was transferred back from Hollenbeck Logistik to IDC.

From the data obtained, the shocks/vibrations were mostly introduced to the packaging at the Duni establishments (Poznan manufacturing and IDC) and lesser when it is being transported, from Poznan to Bramsche. The highest peak of the shock was >16.4g and happen at three different occasions. It happens in IDC and

Hollenbeck Logistik during internal movement or transfer of pallet inside the establishment and during the manual re-palletizing process.

5.2.2 **Bramsche Manufacturing to IDC, Bramsche**

The shock/vibrations were measured from the packing line at production area in manufacturing plant in Bramsche until the building next to it, IDC. However, since the packing line is a full automated system, the logger can only be placed inside the packaging before it is being lifted up to the overhead ceiling conveyor system. Then the reading ended at the IDC after the re-palletizing activity in Hollenbeck Logistik. Figure 40 shows the shock/vibration results recorded by MSR 165.

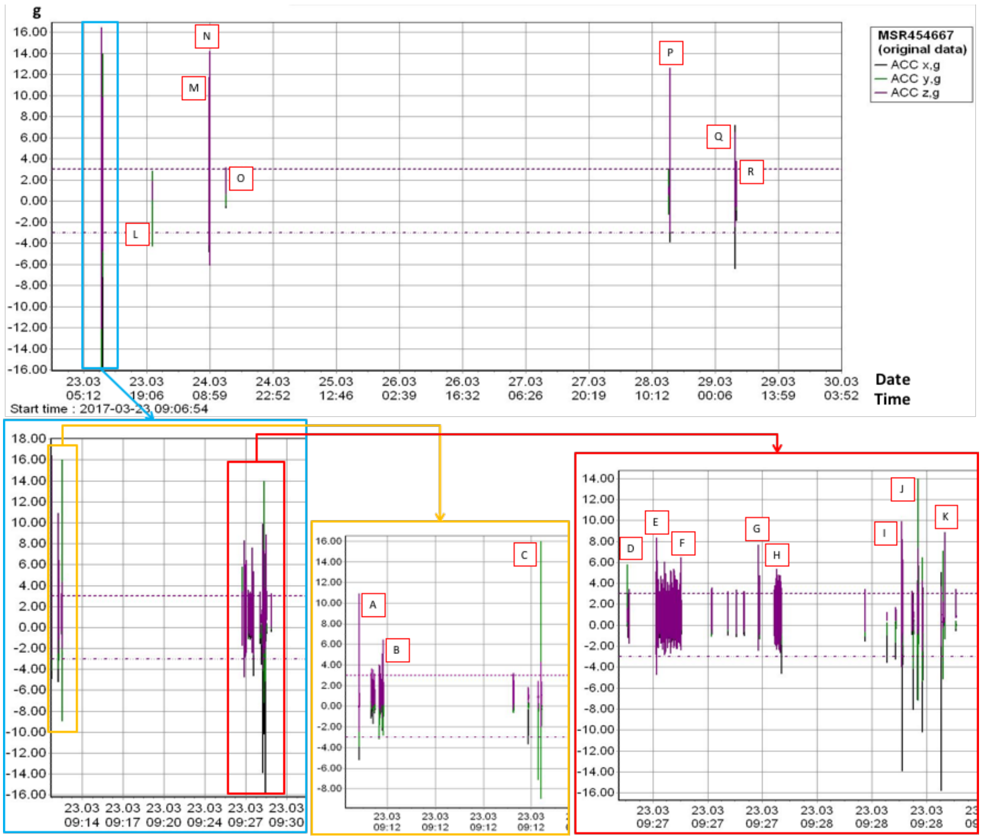

Figure 40. Datalogger A shows shock/vibration results of product B that originally come from Bramsche factory

The description of the shock details as below:

A-H: A, 10.9g; B, 6.4g; C, 16.0g; D, 5.8g; E, 8.3g; F, 6.4; G, 7.6; H, 5.4g; readings come from various part of overhead ceiling conveyor system.

I: 9.9g, roller conveyor to connect overhead ceiling conveyor and palletizing machine.

J: 14.0, when the boxes were pushed onto the metal plate for arrangement of the boxes before being lifted down to the pallet (Figure 41).

Figure 41. Pushed boxes for pallet arrangement

K: 8.9g, happened when 4 boxes being lifted down for palletization purpose.

L: 4.2g, during loading to the process at IDC before being transported to Hollenbeck Logistik for re-palletization.

M: 11.7g, happened when Duni workers manually transferred boxes from Euro size pallet to UK size pallet in Hollenbeck Logistik (Figure 42).

Figure 42. Boxes were manually transferred between different types of pallet

N-R: N, 14.2g; O, 3.2g; P, 12.6g, Q; 7.2g; R, 3.8g; readings happen at Hollenbeck Logistik, suspected during internal movement by forklift.

It can be seen that the process of transporting product B from packing area to palletizing area gave a lot of shocks reading. It can be at the overhead ceiling conveyor or during the arrangement of boxes for palletizing. Even overhead ceiling conveyor gave the highest shock reading of 16.0g. Similar shock trend was observed at Hollenbeck logistics. The activities or movement inside the establishment seems to give a lot of shocks reading. Bear in mind that the logger was not placed from the start of packing process. Hence the mechanical process that the packaging has to go through for e.g. shaping, gluing, closing might give a shock reading as well.

5.2.3 **IDC, Bramsche – Hellmann Logistics – Smithers Pira**

The shock/vibrations were measured throughout the journey of product B from IDC in Bramsche to Hellmann Logistics and the Smithers Pira in United Kingdom. Figure 43 shows the shock/vibration results recorded by MSR 165.

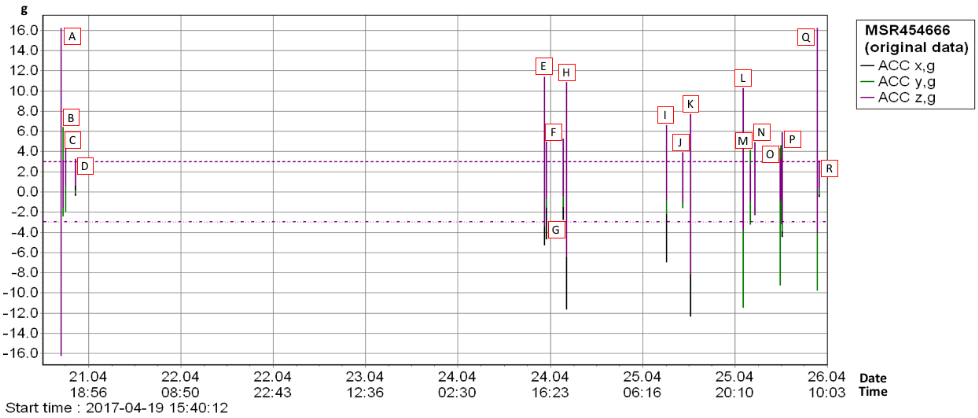

Figure 43. Data logger shows shock/vibration results of product B transported from IDC, Bramcsche to Hellmann Logistics and then to Smithers Pira in UK

The description of the shock details as below:

A: 16.2g, was indicated as internal movement in IDC.

B&C: 6.4g & 4.3g, loading process of product B inside the truck. The products were then transported to Hellmann Logistics in Osnabrück, Germany.

D: 3.3g, happened during unloading process at Hellmann Logistics in Osnabrück, Germany

E: 11.4g, reading took place when product B being unloaded from the truck when it arrived at Hellmann Logistics in Lichfield, UK

F-M: F, 5.0g; G, 5.3g; H, 10.8g; I, 6.6g; J, 3.9g; K, 7.7g; L, 10.3g; M, 4.1; were indicated as internal movement or transfers from one location to another within Hellmann Logistics, Lichfield establishment.

N: 4.9g, when product B was being uploaded inside the truck in Lichfield for delivery to Hellmann Logistics in Colne Brook, UK.

O: 4.6g reading taken place when the products were unloaded at Hellmann Logistics in Colne Brook, UK

P: 5.9g, recorded because of internal movement inside Hellmann Logistics in Colne Brook, UK

Q: 16.2g, unloading process of product B when it arrived at Smithers Pira, Leatherhead.

R: 3.1g, was internal movement or transfer inside Smithers Pira.

Surprisingly throughout the journey of the truck (transportation) from IDC in Bramsche, Germany to the last point which was Smithers Pira in Leatherhead, UK, no shocks or vibrations data more than 3g were recorded. Most of the shocks were recorded at Hellmann Logistics during loading/unloading process or internal movement/transfer within establishment. The internal movement at Hellmann Logistics was mostly due to the fact that the establishment act as transhipment hub, where the delivery was split up according to the order and next location.

5.2.4 **Effect of shock/vibration towards different box positions**

To see the effect of shocks/vibrations towards different positions of the boxes on the pallet, this comparative studies was conducted. Figure 44 and figure 45 show the shocks data recorded throughout the journey of product B from IDC, Bramsche to Hellmann Logistics in Osnabrück, Lichfield and Colne Brook and the last point was at Smithers Pira, located in Leatherhead, UK. Figure 44 demonstrates the logger that was placed inside the packaging at the most bottom layer of the pallet while Figure 45 demonstrates the position of logger at the most top layer of a pallet.

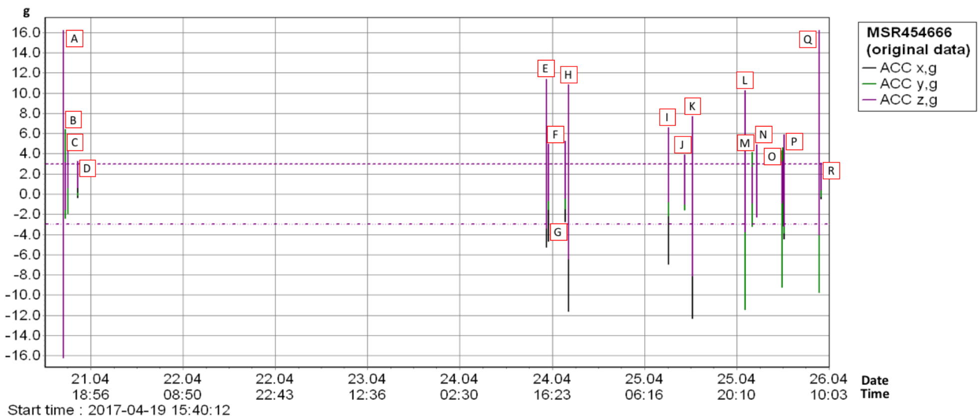

Figure 44. Shocks recorded from bottom layer packaging

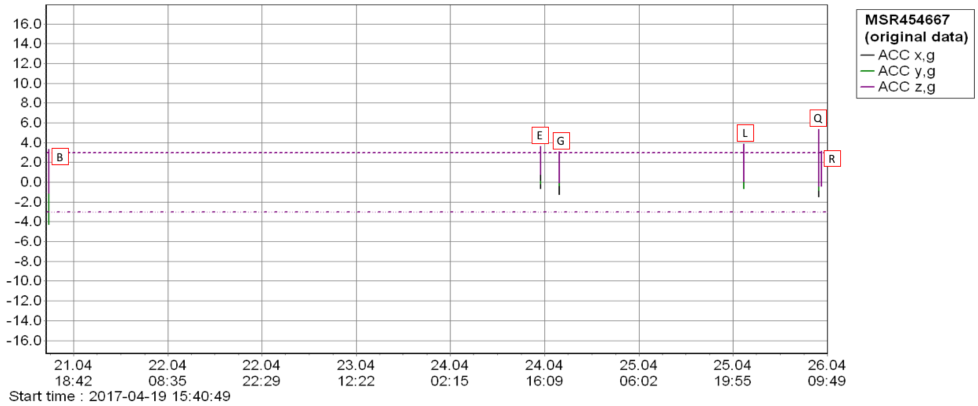

Figure 45. Shocks recorded from top layer packaging

The comparison of the shock reading between bottom layer and top layer packaging is in the Table 5. From 6 point of readings, the table shows that even though both layers might have experienced the shock, but bottom layer always experience greater shock impact in comparison with top layer.

Table 5. Shock readings comparison between bottom and top layer packaging

Locations for shock reading	Shock readings (g)		Percentage differences between bottom and top layer reading (%)
	Bottom Layer	Top Layer	
B	6.4	3.4	47
E	11.4	3.7	68
G	5.3	3.1	42
L	10.3	3.9	62
Q	16.2	5.4	67
R	3.1	3.0	3

5.2.5 **Summarization of findings for shock/vibration**

From the analysis of all data collected from loggers, some conclusion can be done.

1. Both manual handling and automated system able to introduced great amount of shocks or vibrations to the boxes. Manual handlings were mostly depending on the person who handle the packaging. Manual transfer of the boxes from conveyor to the pallet caused shock reading of 5.8g at Poznan manufacturing. However, greater amount of shocks was contributed for the manual handling at Hollenbeck Logistik when Duni staffs were required to re-palletize the boxes

that were in Euro sized pallet to UK sized pallet. From this re-palletizing activity, for product A, shock reading of >16.4g and for product B, shock reading of 11.7g were recorded. For automated system, overhead ceiling conveyor system in Bramsche manufacturing seems like a very good solution to reduce manual handling of the packaging and the need for forklift to transport the goods. However, throughout the overhead ceiling conveyors, there were 8 points of shocks recorded, with a with maximum shock reading of 16.0g. Some improvement in the design of this overhead ceiling conveyor might need to be done to reduce or absorb the shock impact.

2. Transportation by truck, on the road, gave the least shock or vibration impact compare to other logistics activities. From this project, looks like truck as the mode of transportation does not contribute so much towards the shock impact. The only reading recorded during road transport was between Poznan manufacturing to IDC in Bramsche, where 2 shocks of 3.1g and 3.3g were recorded. However, more studies can be done, for example to reduce the setting to trigger the shock to 1.5g. Even though the shock might not be so high in g-force, but if the frequency is high, it might also be able to slowly damage the mechanical properties of corrugated box. As highlighted in the delimitation, data of the transportation by using cargo vessel from China to Germany was unable to be obtained from the studies. Vessel might give different shock impact, compare to truck on the road.
3. Overall, most of the shocks and vibrations recorded during loading and unloading activities of the pallets across the actors in the supply chain. According to Bernad, Laspalas, Gonzáles, Liarte & Jiménex (2010), the stress during transport is the highest during loading and unloading. Loading and unloading mostly happen when the pallets were transferred to the truck or removed from the truck when it arrived at the destination. With this kind of activities, the total 8 shocks recorded for product B with maximum reading of 16.2g. Or, in can also be loading or unloading of the pallets by the forklift to transfer it from one place to another place within the same establishment. For product B, the total of 16 shock readings were recorded with maximum reading of 16.2g. This internal movement or transfer in IDC, Hollenbeck Logistik and Hellmann Logistics in Lichfield shows very high shocks and vibrations reading.
4. The corrugated box located at the bottom layer of the pallet always exposed to higher shocks or vibrations impact compare to other layers. From this studies and as highlighted in Table 5, average of 48% different between the g-force of bottom layer and the top layer from 6 point of shock were recorded. Hence, if the BCT studies were conducted, box from bottom layer should be selected as the sample for the studies.

5.3 Relative Humidity (RH) and Temperature (T)

Relative humidity is a measurement of water vapour but relative to the temperature of the air. It is indicated as the amount of water vapour in the air as a percentage of the total amount that could be held at its current temperature (DeTorres, 2014). As highlighted before, one weakness of the corrugated board would be its moisture permeability and the ability to absorb water. Hence it is important to know the relative humidity reading across the supply chain.

None of the supply chain actors in Europe that involved in this project have a proper climate control system inside their warehouse or distribution centre. Hence, relative humidity (RH) and temperature (T) were not measured by them. Data loggers MSR165 were used for this project since the actors unable to provide the RH and T data. In Poznan and Bramsche, the warehouse used to store incoming raw material such as flat corrugated cardboard boxes were also without climate monitoring. As highlighted by Trost & Alfthan (2016), common test method inside the laboratory are using the standard climate of 50% RH, 23 °C and the effect of other climates toward corrugated box performances were not properly studies. But, logically the higher the relative humidity, the more deterioration on the corrugated box's strength.

Figure 46 – 48 show the relative humidity (RH) and temperature (T) reading in this project. By benchmarking ISO standard test atmosphere for testing of pulp, paper and board which is 50% RH, 23 °C, it can be seen that only some data in Figure 47 exceeds the relative humidity standard of 50%. Average reading of each result is demonstrated in Table 6.

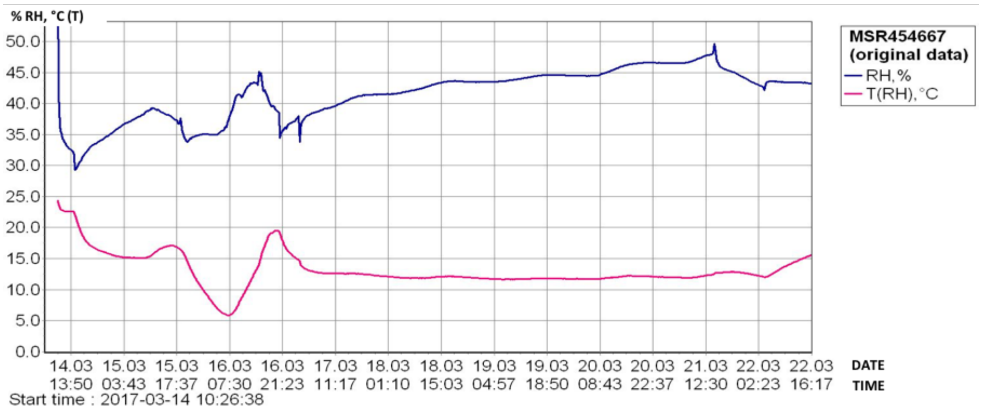

Figure 46. Relative humidity and temperature results from Poznan - Bramsche

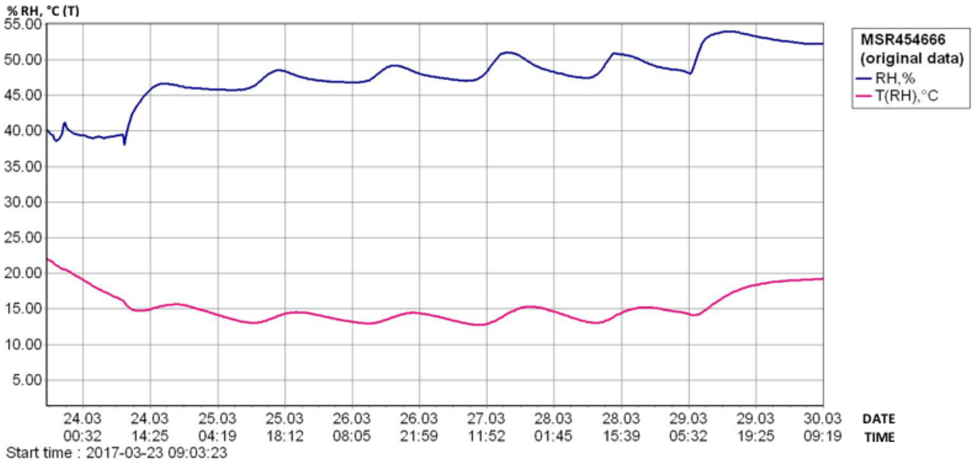

Figure 47. Relative humidity and temperature results in Bramsche

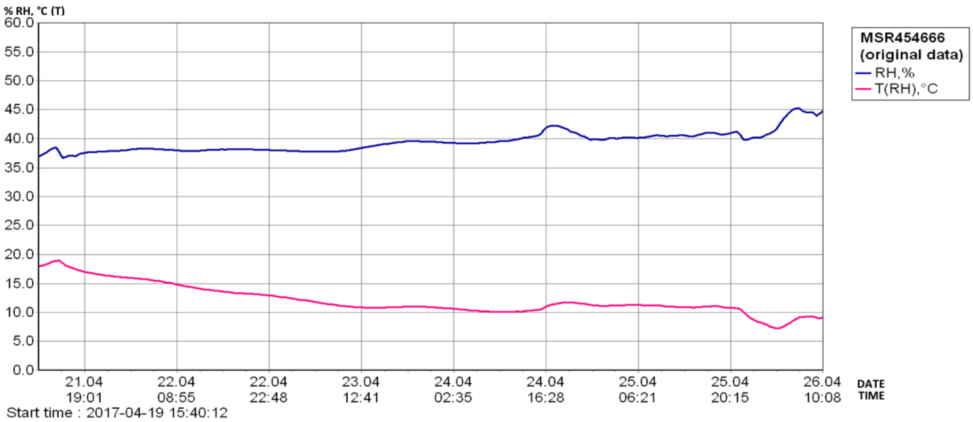

Figure 48. Relative humidity and temperature results from Bramsche - UK

Table 6. Average RH and T readings for this project

Figure	Descriptions	Average	
		RH, %	T, °C
Figure 46	Results across the supply chain from Poznan - Bramsche	41.4	13.2
Figure 47	Results across the supply chain in Bramsche	47.8	15.7
Figure 48	Results across the supply chain from Bramsche – UK	40.6	13.8

Based on Table 6, it is safe to say that throughout the project, the RH result can be considered as good. This is due to average RH recordings were below 50%. These measurements were taken in March and April 2017 from 3 different locations which are Poland, Germany and United Kingdom; hence it is not representative of the climate throughout the year. Not only the time of the year that have different climate but also different locations might give different reading of relative humidity.

Even though as highlighted in delimitation section earlier that relative humidity and temperature results from data loggers travelling from China to Germany were not obtained, literature studies show that the average relative humidity in Guangzhou was 68% in a year (National Bureau of Statistics of China, 2006) which is quite high compare to the relative humidity results obtained in Europe for this project. Guangzhou is the capital city of Guangdong and Shenzhen (location of Supplier A) is a sub-province of Guangdong. Not to forget, unlike warehouse, the relative humidity inside cargo vessel can drastically change because of rapid temperature fluctuations. If this happen, it can lead to container rain and cargo sweat problem (Roche, 2013). At higher levels of relative humidity, above 80%, corrugated boxes start to soften (Inside a container, 2014). This is what product C that come form China might have to faced when it is transported by cargo vessel from Shenzhen port, China to Hamburg port, Germany.

According to Gustafsson & Nyman (2005), experiment shows that the higher the RH, the lower strength of the box observed. 50% RH have the highest strength, follow by 70% RH and 90% RH have the lowest strength. Hence, it is suggested for Duni to continue with this climate studies especially for their traded goods that come from outside Europe. This is because, it is proven that RH give an impact towards the packaging strength. The future studies can also be conducted with actual duration of product storage inside the warehouse as influence of moisture is greater at longer storage time (Gustafsson & Nyman, 2005).

5.4 Box Compression Test (BCT) results

The main measurement for the unit analysis for this studies, corrugated box strength was done by using Box Compression Test (BCT) machine. From the result obtained in Table 7, the value in Newton (N) of strength reduction in corrugated box across the supply chain can be seen. The measurements were taken at 2 places which were Bramsche manufacturing, to demonstrate the strength reduction of the corrugated box when its travelled from the manufacturing establishment to the Duni International Distribution Centre (IDC) in Bramsche, Germany and the second place would be at Smithers Pira in Leatherhead, United Kingdom to demonstrates the further reduction of the corrugated box strength when it reaches end customer.

Unused corrugated box BCT measurements were also conducted in Bramsche manufacturing to demonstrated the initial strength value possess by the corrugated box before it is being used. Unfilled test was conducted by removing out the product from the box, thus the box will be emptied. Then, the result from unfilled boxes were compared with unused box to see the corrugated box strength reduction. From the result, it is shown that the corrugated box strength reduced across the supply chain. Filled box test was conducted to see the contribution of the product or primary packaging inside the corrugated box in supporting the box towards compression given to them.

Table 7. BCT results for corrugated boxes

Location of BCT		Bramsche Manufacturing			Smithers Pira		
Descriptions		Days after prod.	BCT result (N)	Safety factor	Days after prod.	BCT result (N)	Safety factor
Box originated from Poznan (Product A)	Unused		1407	8.3			
	Unfilled	31	1347	8.0	44	1254	7.4
	Filled		1343	8.0		1314	7.8
Box originated from Bramsche (Product B)	Unused		2552	3.9			
	Unfilled	19	2274	3.5	35	1584	2.4
	Filled		3278	5.0		2912	4.5
Box originated from Supplier A in China (Product C)	Unused		2249	3.8			
	Unfilled	43	2064	3.5	48	1850	3.1
	Filled		5469	9.3		5457	9.2

It is clearly shown that the strength of the corrugated box reduced as the packaging goes further along the supply chain flow. The unused box originated from Poznan came with a value of 1407 N, safety factor (SF) 8.3 and reduced to 1254 N, SF 7.4 with a 11% of reduction. The strength reduction cause by several factors. Manual palletizing activities might reduce the corrugated box strength, however that was not the biggest contributor. The re-palletizing activities and internal movement that took place in Hollenbeck Logistik might contributed to a lot more of strength reduction. The biggest contributor in strength reduction for this box originated from Poznan might be due to many loading and unloading process and pallet movements throughout the supply chain actors.

It is also interesting to see that the filled box for packaging originated from Poznan does not help in improving the corrugated box resistant towards the compression. For example, when the box was tested in Bramsche manufacturing, when the compression was given, it gave the same SF as unfilled box. This shows that the product that it contained does not help in improving or assist in packaging strength. This was aligned with the finding that packaging for product A was designed poorly, with a lot of air inside the packaging, unnecessary head space and a lot of gaps in between the product, that eventually might lead to dented vertical edge of the corrugated box. Gardner & Cooper (2003), have shared a case study in ESAB (produced welding rods) shows that extra air inside the box can cause the pallet to collapse and gave more instability to the pallet. The case also stated that, due to the extra space in individual corrugated box, the content only able to partially support the load from above.

The unused box originated from Bramsche came with a value of 2552 N, SF of 3.9 and reduced to 1584 N, SF 2.4 with a 38% of reduction. Besides having similar problem like product A – several loading and unloading process throughout the supply chain significantly impacted the reduction of packaging strength, reduced strength of corrugated box strength for product B was also observed in the production/packing line. As highlighted before, overhead ceiling conveyor system in Bramsche manufacturing contributed to a lot of shocks reading, thus lowering the corrugated box strength. Beside that, the automated palletizing machine in Bramsche manufacturing was also giving some high shock readings that might contribute to even more reduction of corrugated box strength.

Figure 49. Self-open perforation observed happened at shelf ready packaging of product B

Unlike packaging for product A, the corrugated box for product B seems to have better support from the product that it contained. BCT results of filled corrugated box of product B in Bramsche manufacturing shown a SF of 5.0 which was higher than the SF value for the unused packaging. However, even though the product that it contained gave a good support to the packaging from the compression given, when it was tested it Smithers Pira, the SF for the filled packaging reduced from 5.0 to 4.5. This probably due to perforation of corrugated box had been self-opened during the supply chain process from Germany to United Kingdom (Figure 49). This self-open perforation most likely to happen at the bottom layer of the pallet. As highlighted by Trost & Alfthan (2016), perforations weaken the box but in a way that is difficult to predict.

The unused box originated from Supplier A came with a value of 2249 N, SF of 3.8 and reduced to 1850 N, SF 3.1 with a 18% of reduction. Beside having similar problem like product A & B – several loading and unloading process throughout the supply chain that impacted the reduction of packaging strength, the reduced strength of corrugated box for product C might also have been contributed by the cargo vessel transportation from Shenzhen, China to Germany. However, since the data loggers' result is unable to be obtained by researcher, it is hard to pinpoint the exact root cause that leads to reduction of packaging strength.

Similar to product B, the corrugated box for product C have a good support from the product that it contained. BCT result of filled corrugated box of product C in Bramsche manufacturing shown a SF of 9.0 which was higher than the SF value for the unused packaging. If we compare the results difference between filled and unused corrugated box of product B and C during BCT in Bramsche manufacturing, corrugated box for product C performed better with 59% difference in comparison to corrugated box for packaging B with 22%. The bigger percentage might be due to the primary packaging for product C was a cardboard box filled compactly with 2000 stirrers. Compare to product B that have a primary packaging of PP plastic that wrapped 125 napkins. Hence the rigid structure of compact cardboard box for product C helps the secondary corrugated box to be able to stand higher level of compression, thus increasing the safety factor to 9.3.

5.5 Recommendation to revise the safety factor (SF)

From Box Compression Test results and discussion in Section 5.4, a decision tree as demonstrated in Figure 50 is created in order to help Duni in reviewing and revising their safety factor. In Innventia public report 2016, it is stated that safety factor is based on experience and have very large uncertainties. This statement was proven right with this project. Duni struggled to come out with a proper safety factor in order to overcome the reduction of corrugated box strength due to high uncertainties found throughout the supply chain. At the moment, Duni is using standard safety factor of 4 for their European chain packaging and standard safety factor 4.8 for Asian chain. However, this safety factor standard was only used for a packaging of new products developed or problematic packaging and not for existing packaging. That is why, in this project, the SF of unused corrugated box in Poznan can be 8.3, 108% more than the standard SF of 4.0 for Duni European chain.

In designing a packaging as a part of new product development or when improving the existing corrugated box performance, it is suggested to always conduct a Box Compression Test (BCT). This BCT is important to indicate the performance of the packaging. If it is found that the content of the corrugated box (primary packaging or products) helps in providing mechanical support to the corrugated box from the compression given, hence, the corrugated box is well designed and will be able to fit the product nicely. However, if the filled corrugated box performed poorly than unused corrugated box, this can be seen as a signal that the corrugated box was not well designed.

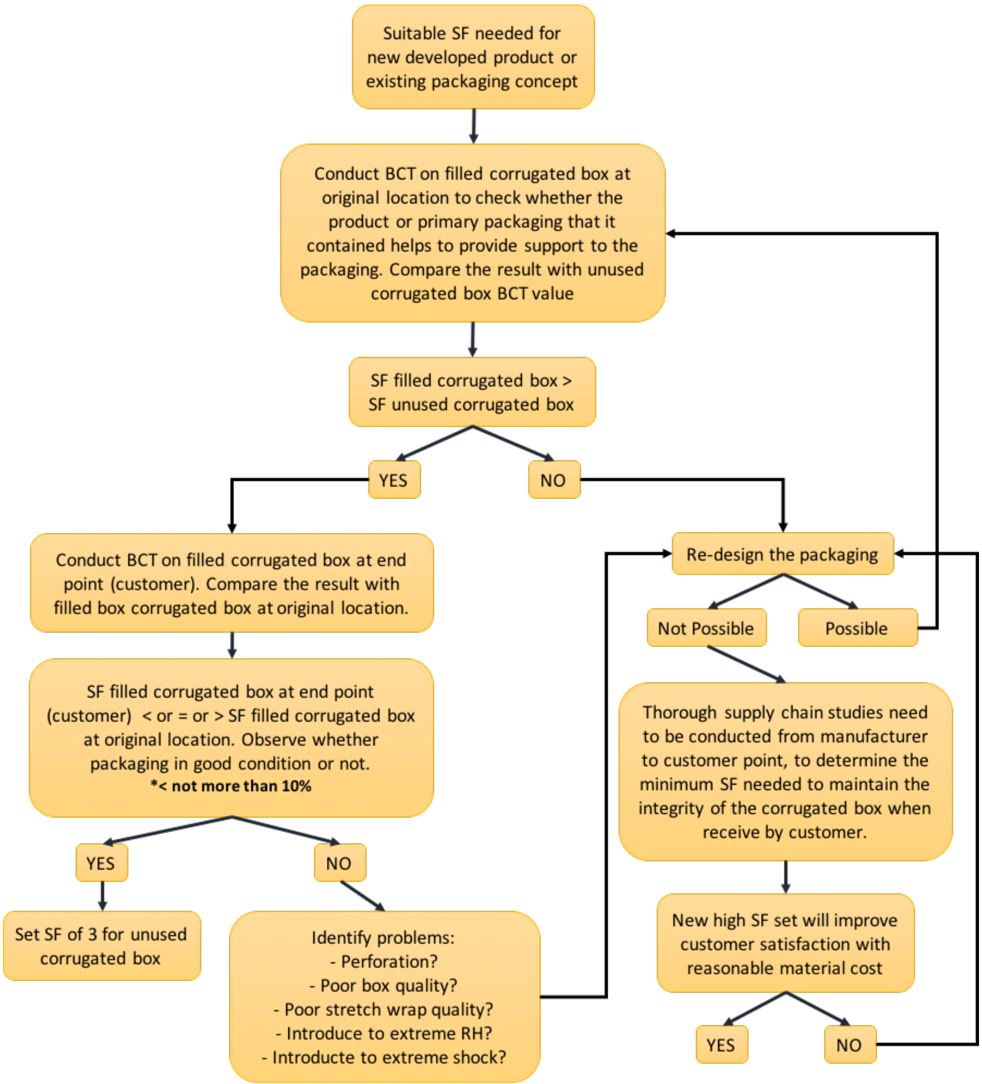

Figure 50. Decision tree to determine the suitable safety factor (SF) for corrugated box

To make sure that the corrugated box performs as expected until it reaches customer, observation of the box condition should be done at the end point of the supply chain process. In order to double confirm on the performance of the corrugated box, a second BCT on filled box can also be conducted at the end point. The results logically should be similar or slightly reduced against the BCT value of the filled box measured at the original point. If it is reduced, this might be due to the nature of the corrugated box. 10% allowance for the reduction of BCT values for filled product at the customer point should be given. This 10% allowance is established by looking at the performance of packaging originates from Bramsche as a benchmark. However, it is important to observe the box and see whether any problems related to the corrugated box such as self-open perforation or poor stretch wrap quality present. After identifying the problem in details, for example, perforations for different box designs and the effects of horizontal and vertical perforation patterns (Trost & Alfthan, 2016), the packaging might need to be re-designed for improvement.

Based on the rule of thumb in the corrugated industry that the corrugated box's safety factor should be between 3 and 5 (Corrugated Compression Strength, 2017). Hence, if the packaging has a good support from the product that it contained and at customer point observation, the packaging is still in the good condition, this corrugated box is at its optimum performance. Thus, Duni can set the safety factor for that particular packaging as low as safety factor of 3. This is because, the possibility of the filled box packaging strength to be lowered than 3 is quite impossible with this kind of packaging. Moreover, Duni can reduce the materials cost needed for this type of packaging.

If at original point, the BCT result of filled corrugated box has a value lesser than the unused corrugated box, this is a good indicator that the product or primary packaging that the corrugated box contained does not help in providing a good support to the box. Hence, the packaging design or any other criteria that related to the corrugated box should be improved. If it is not possible to re-design the packaging, thorough studies on the performance of the corrugated box across the supply chain need to be conducted. The safety factor for this packaging cannot be simply pre-determined. This is because, by taking the packaging originated from Poznan as an example, even though it has a safety factor of 8.0 for filled product, 100% more than Duni standard of 4.0, the packaging still ended up dented at the vertical edge of corrugated box, which is visible from the customer point. This proves that, it is not easy to set the safety factor for this kind of packaging unless proper studies are conducted across the supply chain.

To save cost on safety factor studies, alternatively Duni can choose a high runner product from one manufacturing establishment and measure the BCT reduction when it arrived to the end customer. From this reduction, new safety factor can be established for this packaging. By benchmarking of this packaging, other packaging that have more or less the same weight and size, and undergo the same supply chain process, can have the same safety factor value. However, bear in mind, eventhough with a newly set high safety factor – the optimum packaging performance can be reached, but it might increase the material cost of the corrugated box drastically. Hence, if high material cost is a problem for Duni, it is strongly recommended, to re-look at the possibility of re-designing the packaging.

6 Conclusion & Future Research

In order for Duni to achieve appropriate safety factor for corrugated box that eventually will help in their delivery performance with optimal lead time, Duni could follow the recommended decision tree that derived from the thorough data collections of shocks and vibrations, relative humidity and Box Compression Test (BCT) in the supply chain. To do this, all business units and operation departments in Duni should work together in delivering a good product with a good packaging and close all the gaps in Duni's supply chain system.

It is important that Duni does not over pack or under pack their product. Working together with academia is a positive effort shown by Duni. This master thesis can be used as an overview or indicator of what is happening in Duni's packaging system throughout the supply chain. Future studies in corrugated box strength and its performance can be focused in three aspects:

1. As highlighted in recommended decision tree for safety factor determination, product or primary packaging that the corrugated box contained plays an important role in providing additional mechanical support to the corrugated boxes from the pressure or compression that were applied to them. Hence, further studies are needed to see the interconnection and interaction of product, primary packaging and secondary packaging along the supply chain, in order to improve the design and functionality of each entity.
2. Loading and unloading process introduced the most shocks and vibrations in this project. Hence, it is an advice for Duni to study on the possibilities in minimizing supply chain actors, thus promoting leaner supply chain process. Example, Hollenbeck Logistik might not be needed if Duni manage to invest on re-palletizing machine (Euro pallet to UK pallet) in IDC. Or, Duni can investigate whether it is necessary to have three transhipment locations (Hellmann Logistics in Osnabrück, Lichfield and Colne Brook) for products journey from IDC in Germany to their customer in United Kingdom.
3. Duni can also do a further study on the ageing effects of the corrugated box by conducting a project that follows an actual lead time of the products. To make it more interesting, the study can be conducted outside Europe, in a different continent and with various mode of transportation. Just like in this project, data logger can be placed inside the corrugated box to see shocks, vibrations and relative humidity along the supply chain. GPS tracker can also be used to facilitate the investigation process on which point of the supply chain process need the most attention due to the results given by the data logger.

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Appendix A : Supplier A Instruction

CONTENT

1. Introduction:

In order to further improve customer satisfaction, Duni decided to evaluate the impact of transport routes and handling activity on the quality of the secondary packaging from Asia to Europe. As [redacted] is a highly valued supplier in the Asian region, [redacted] is selected to support Duni in this project

2. Project brief:

Impact of the logistic activities to the stackability of the packaging system - To understand, evaluate and overcome the stackability issue of the finished goods by suggesting possible improvement in the area of packaging system and logistic activities.

3. Contact persons:

Syahir Suhaimi: Syahir.Suhaimi@duni.com
Reine Alm: Reine.Alm@duni.com
Wilbert Baerwaldt: Wilbert.Baerwaldt@duni.com

4. Methods:

- Analyzing Relative Humidity (RH), temperature, vibration and shock – Logger MSR 165
- Tracking the route – GPS Xtreme GM7
- Strength of the box – Box Compression Test (BCT) machine
- Supply Chain activities – Through picture + description and interview (email & skype)
- Packaging audit – Questionnaire will be sent by email

5. Traded Good:

Articles number: 153522
Product name: Stirrer box 112mm White

6. Task

Four major tasks for this project:

Section A: Sending 45 SKUs to Duni warehouse in Bramsche, Germany in week 10. The 45 SKUs expected to arrive in Bramsche on Week 15 (page 3 – 7 for instructions)
2 SKUs/boxes to placed logger MSR 165 and GPS Xtreme GM7, BCT
43 SKUs/boxes for Box Compression Test

Section B: Sending 25 flat unused corrugated boxes (secondary packaging) to Duni warehouse in Bramsche, Germany as soon as possible. The flat unused corrugated boxes need to be in Germany on week 12.
For Box Compression Test

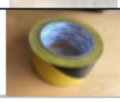
Section C: Sending pictures and descriptions of every activity in supply chain. This will capture everything that is happening in Section A. Send the pictures and descriptions through email.
For packaging & logistic process audit

Section D: Answer the questionnaire that will be given in another email.
For packaging & logistic process audit

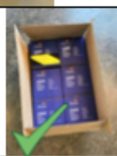
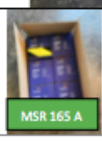
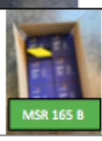
SECTION A

Sending 45 SKU to Duni warehouse in Bramsche, Germany in early week 10 (on Monday 7th March if possible) – For logger MSR 165, GPS Xtreme GM7, BCT

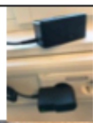
You can find the below items from the box sent by Duni Malmö

No	Items	Pictures
1	Data Logger MSR 165 with label A	
2	Data Logger MSR 165 with label B	
3	USB cable for MSR 165	
4	GPS tracker Xtreme GM7	
5	Charger for Xtreme GM7	
6	Velcro	
7	Warning tape (yellow/black stripes)	

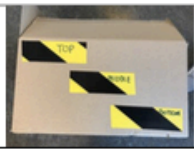
A. Installation of MSR 165 logger inside the packaging

No	Description	Picture
1	Charge MSR165 A & B, until the yellow light disappears. You can connect directly to power supply or pc/laptop. The charging will only take about 30 minutes.	
2	Logger MSR 165 A & B comes with velcro stick at the bottom. Another set of velcro should be stick inside the primary packaging.	
3	Remove out some stirrer to make space for the logger. Install the logger inside the primary packaging as shown in the picture.	 
4	Press the blue button located at top part of the logger for 4 seconds until the blue light blinking 5x. After that it will blink once/5 seconds to indicate that the logger is ON. **Remember! Double blink/5seconds means the logger is still OFF. IF there is red light blinking once/5secs together with the blue light, that is OK. Red light indicates alarm.**	
5	Closed the box and put the warning tape around the box as shown in the picture.	
6	The box will then be placed inside the corrugated secondary packaging with other boxes. Follow the arrangement shown inside the picture to ensure that the logger located at the bottom of the box not at the top.	 
7	Mark corrugated box with "X" using the warning tape. Do this mark at every side of the box (4 sides)	
8	Do steps 1-6 for both logger A & B. Logger A and B must be located in the different secondary corrugated box	 

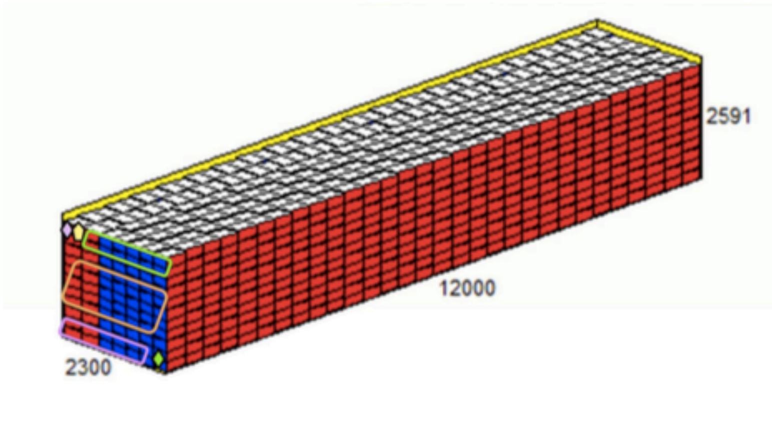
B. Installation of GPS Tracker Xtreme GM7 inside the packaging

No	Description	Picture
1	Charge the GM7 for 2 hours	
2	Wrapped GM7 with bubble wraps	
3	Remove out some stirrer to make space for the GM7. Placed GM7 in between the stirrer.	
4	Closed the box and put the warning tape around the box as shown in the picture.	
5	The box will then be placed inside the corrugated secondary packaging with box containing MSR 165 A. Follow the arrangement shown inside the picture. **Remember! GM7 will be in the same corrugated secondary packaging with MSR 165 A**	
6	Mark corrugated box with "X" using the warning tape.	

C. Marking of boxes for BCT test

No	Description	Picture
1	Packed the product as usual. **43 boxes** of SKU/secondary package will be needed for this marking. **Remember! The total of delivery is 45 boxes but 2 boxes already used for the MSR 165 and GPS GM7**	
2	8 packages will be labelled as top 27 packages will be labelled as middle 8 packages will be labelled as bottom	
3	Use warning tape, measure about 6 inch and paste the warning tape at each side of the box (4 sides). Depending on the label (top, middle, bottom), the sticker should be placed as shown in the picture. Do this for all 4 sides of the box.	
4	Use marker pen and write top/middle/bottom on the warning tape.	

D. Arrangement inside the container/cargo

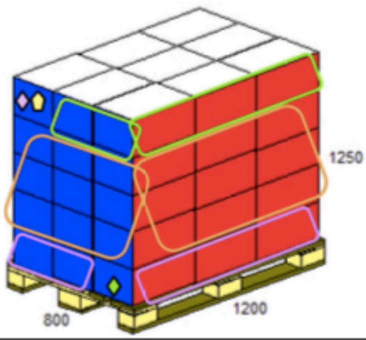


- 1 Box with MSR 165 A & GPS GM7
- 1 Box with MSR 165 B
- 8 boxes label with top for BCT
- 27 boxes label with middle for BCT
- 8 boxes label with bottom for BCT

All of the boxes for this project need to be arranged nearby the door of the container/cargo

Remember! Box containing MSR 165 A and GPS GM7 MUST be located at the most top part of the container to make sure a good GPS signal transmitted.

E. Arrangement on the pallet



- 1 Box with MSR 165 A & GPS GM7
- 1 Box with MSR 165 B
- 8 boxes labelled with top for BCT
- 27 boxes labelled with middle for BCT
- 8 boxes labelled with bottom for BCT

Remember! Box containing MSR 165 A and GPS GM7 MUST be located at the most top part of the pallet to make sure a good GPS signal transmitted.

Appendix B : Structured Questionnaire

Questionnaire

Manufacturer / Supplier

Name:
Job title:
Company and location:
Phone:
Email:
Article number:
Product/SKU name:

1. Packaging Scorecard Weight

Give each criterion below weight of 0-100%.The importance of the criterion increase as the weight increase. 100% is for very important criterion while 0% if the criterion is irrelevance. New criteria can be added.

Criteria	**Weight (0 – 100%)**
Machinability Ability of the packaging to be processed effectively in production line	
Product Protection Ability to protect the product in different environments e.g. mechanical stress	
Handleability Ability to facilitate handling e.g. fill, store, transport, lift, close, empty	
Flow information Capability of the packaging to give correct information in supply chain	
Stackability Ability to stack many pallets/shipments units, e.g. in warehouse, during transportation	
Volume and weight efficiency Ability to make use all the available volume and load capacity in packaging system	
Right Amount & Size Quantity in the packaging system adapted to turnovers and logistical requirement	
Safety (protect the product from theft) Ability to protect the product from theft e.g. during storage in the warehouse, truck	
Reduced use of resources Reduce load to the environment e.g. excessive packaging materials	
Minimal amount of waste Amount of waste from the packaging that might increase the waste management cost	
Minimal use of hazardous substances Packaging contains minimum hazardous substance that might be harmful to customer and environment	
Packaging cost The direct cost of packaging	

2. Packaging Scorecard Questionnaire

The focus of this questionnaire is to know the performance of primary packaging, secondary packaging and tertiary packaging across the supply chain.

Packaging level description

Describe each packaging level in brief. (Size, materials, safety factor, BCT/stackability, etc.)

1. Primary packaging
2. Secondary packaging
3. Tertiary packaging

Machinability

Only answer this part for packaging level that involved in machine/automated packing. Skip manual packing.

1. Do you have filling operation that is done automatically by machine? (focus on packaging only e.g. primary package fill into secondary package)
2. Number of production and packaging lines for selected article/product. Did the packing line shared with other product? If yes how many?
3. If it is a shared packing line, do you need to do adjustment on the machine every time you changed product? If yes, in average how long do you take for the adjustment?
4. How frequent the packing machines need to be restart per day because of the package problem? In average how long is the restarting time?
5. How many number of non-schedule (unplanned) breakdowns per month for the packing machine? What is the major root cause?
6. Do you have a lot of packaging waste when you pack the product? What happen to this packaging waste?
7. Overall, do you think that the current packaging can be packed efficiently using the current machine? Do you have any suggestion for improvement? The suggestion can be both packaging design and machine capability.

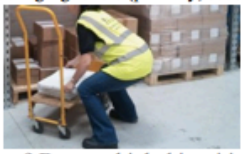
Product Protection

Answers should cover all packaging levels (primary, secondary and tertiary)


1. Does the packaging meet the demands for product protection (mechanical, climatic)?
2. Do you get returns because of damaged packages? Do you have any statistics?
3. How much efforts are putting into improving the mechanical properties of the packaging?

4. Which part of filling process might lower down the strength and damaged to the package?
5. Do you think the current packaging design able to improve the keeping qualities of the product? Any suggestion for improvement.

Handleability
Answers should cover all packaging levels (primary, secondary and tertiary)

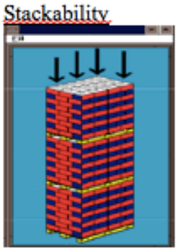



1. Which are critical steps? Do you think this critical steps can damaged the packaging?
2. Is the packaging easy to handle (carry, lift, drag, stack, label, re-load, etc.)?
3. Which moments the packaging must be carried out manually?
4. Do you think that you have too many manual handling? Do you think manual handling contribute to longer time of processing?
5. Do you think that the packaging is ergonomically designed? Any suggestion for improvement.

Flow Information
Answers should cover all packaging levels (primary, secondary and tertiary)

1. Is there barcode on all packaging levels?
2. Number of barcode reading operation in the flow? Who mostly responsible in scanning/reading the barcode?
3. What kind of barcode or system that you used?
4. Do you keep statistics of packaging related complaints?
5. Do you think with current flow information system that you have can avoid theft?
6. Suggestion for improvement?

Stackability



1. Do you stack the finished goods pallets inside your manufacturing plant or in your own warehouse before the product being shipped out? Please include pictures.
2. How many stacking it usually be? Double, triple stacking? In average how long the duration of this stacking?

3. In your opinion, do you think stacking can give negative impact to packaging strength and damaged the packaging? Any idea for improvement?

Volume & Weight Efficiency

1. State the volume efficiency on the whole or half pallet (if any).
2. What design changes can be made to reduce size and weight without reducing quality?
3. Are the packaging system properly volume and weight adapted to suit distribution and customer demands?
4. Weight demands and how does the packaging system meet them?

Right Amount & Size

1. How often do you get an obsolescence report? (the product need to be destroy/ ride-off)
2. State the inventory turn-over rate of the finished goods
3. Where in the flow of the product do you get complaints about wrong size or number?
4. Do you think you have right number and amount of products on pallet or are there a room for improvement? (maybe to add or reduce number of product)

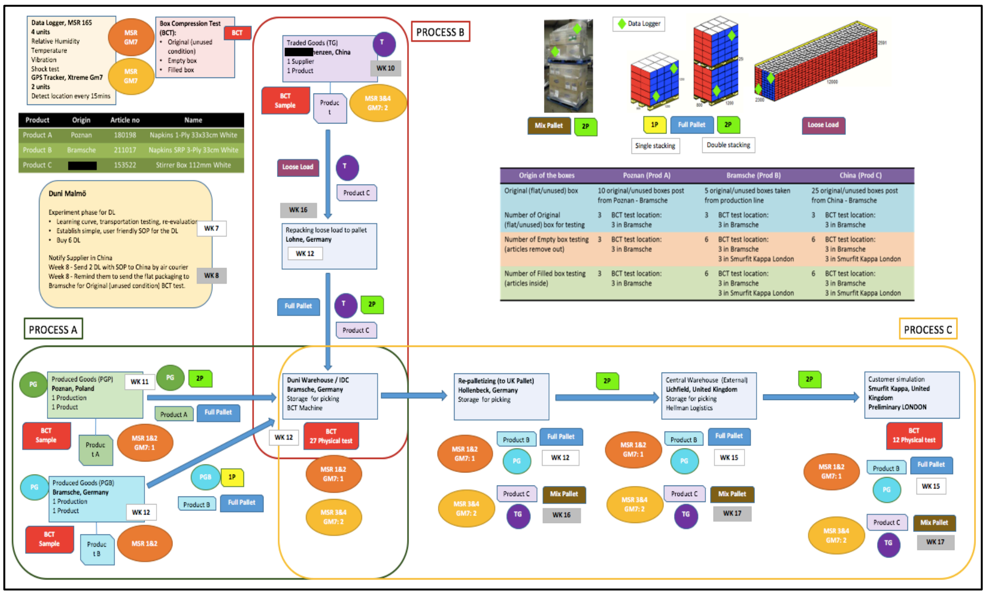
Other value-adding properties
Refers to other functions than the basic requirement on the packaging

1. Are there any additional value-adding properties of the package used in the filling process or improved the packaging across the supply chain?

Minimal amount of waste

1. How long time does it take to break and take care of the shop package

Appendix C : Project Planning



Product	Origin	Article no	Name
Product A	Poznan	180198	Napkins 1-Ply 33x33cm White
Product B	Bramsche	211017	Napkins SRP 3-Ply 33cm White
Product C	[redacted]	153522	Stirrer Box 112mm White

Origin of the boxes	Poznan (Prod A)		Bramsche (Prod B)		China (Prod C)	
Original (flat/unused) box	10 original/unused boxes post from Poznan - Bramsche		5 original/unused boxes taken from production line		25 original/unused boxes post from China - Bramsche	
Number of Original (flat/unused) box for testing	3	BCT test location: 3 in Bramsche	3	BCT test location: 3 in Bramsche	3	BCT test location: 3 in Bramsche
Number of Empty box testing (articles remove out)	3	BCT test location: 3 in Bramsche	6	BCT test location: 3 in Bramsche 3 in Smurfit Kappa London	6	BCT test location: 3 in Bramsche 3 in Smurfit Kappa London
Number of Filled box testing (articles inside)	3	BCT test location: 3 in Bramsche	6	BCT test location: 3 in Bramsche 3 in Smurfit Kappa London	6	BCT test location: 3 in Bramsche 3 in Smurfit Kappa London