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Risks in global transport

Faycal Sadki and Paul Mergin Singaraja

Product Management

Master’s thesis

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ABSTRACT
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Abstract

The background of this project is that the case company delivers its products to customer all over the world using different supply chains. Currently, the products are packed and shipped in relatively similar packages without considering the specific requirements of the various supply chains, which raises the concern of poor packaging performance. Meaning that the packaging system was not designed to meet the supply chain requirements which ultimately leads to product damage or quality deterioration.

The purpose of this thesis is to define the conditions that the product and the industrial package are exposed to in the various supply chains, as they flow from the Alfa Laval facility in Lund to the customers. The identification of the supply chain conditions will provide essential data that can be used as a foundation to enhance the industrial package's performance and increase the protection of products during transport.

The methodology used is an abductive research using systems thinking, in which theoretical knowledge was combined with empirical data collected through various methods to answer the research questions and provide suggestions for improvements. The data collection methods were interviews, observations, internal documents examination, data loggers and GPS trackers.

The Conclusions were that the product and the industrial package are exposed to various risks that can be classified as mechanical, chemical & biological or miscellaneous risks. The occurrence of risks and the extent of damage they can cause are influenced by factors related to the product & its package, the communication between the forwarders, the climatic conditions, the human factor and finally factors related to activities of transport, handling & storage. The shipped cargo was exposed to high humidity shocks throughout the different supply chains. The cargo was not exposed to more damaging conditions in developing countries, as high humidity levels and shocks were also recorded within the production facility in Lund and during handling in EU countries (e.g. at ports).

Additional Information

Keywords: Packaging, logistics, risks, transport, supply chain

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Lund, May 2018

Faycal Sadki and Paul Mergin Singaraja

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ABBREVIATIONS

3PL	Third Party Logistics
G-Force	Gravitational Force
GPHE	Gasketed Plate Heat Exchanger
RH	Relative Humidity
SLA	Service Level Agreement

1 INTRODUCTION

1.1 The case company (Alfa Laval GPHE)

Alfa Laval AB is world leader in key areas such as Heat transfer, Separation and Fluid handling. The company sells their products to customers around the world and their headquarters is located in Lund, Sweden. Alfa Laval is a manufacturing company and consists of global sales and service operations. Their market strategy is that the sales team works closely with the customer. Supply chain operations such as logistics and packaging are provided by third party companies. Alfa Laval works with business to business deals and in this report the researchers will work with Gasketed Plate Heat Exchanger which is a product manufactured by Alfa Laval Gasketed Plate Heat Exchanger (GPHE) group which is a part of Alfa Laval AB. Alfa Laval GPHE is driven by the customer needs to achieve better product quality, higher efficiency and greater serviceability. The main manufacturing process is done in house at Alfa Laval GPHE. However, Alfa Laval GPHE does not have the entire control over their supply chain in terms of shipping the product to the customer, as this is done by third party logistics organisations. Considering how the packaging plays a major in the supply chain, Alfa Laval GPHE wants to better understand the role of packaging and the risks it is exposed to in the supply chain. The ultimate goal for Alfa Laval is improving the efficiency and effectiveness of their packaging system in a way that will provide a better protection and enables the product to reach the customer in optimal conditions. As this will play an important role in achieving customer satisfaction.

1.2 Project background

Alfa Laval Gasketed Plate Heat Exchangers (GPHE) is a branch of the Alfa Laval group which has a global presence and supplies a variety of products to its customers located all over the world. This implies that the packages sent to customers around the world are exposed to different kinds of risks related to rough climate conditions, challenging handling methods and infrastructures. However, currently the products are packed and delivered in a relatively similar way to all customers with some differentiation between supply chains requirements on the industrial packaging in different contexts. At the moment, Alfa Laval GPHE does not have clear specifications about the characteristics of the different supply chains used to deliver the products to customers, as well as the subsequent requirements these supply chain characteristics put on the packaging. The term supply chain characteristics refers to the characteristics of the transport routes, the transport modes used and the transport related operations in different conditions. Noteworthy that the transport operations makes reference to all activities involved in delivering the industrial package to the customer such as picking, moving, storing, loading and unloading, strapping the package to the cargo container or truck bed.

This current situation of not having a clear understanding of the supply chain characteristics in different conditions e.g. how industrial packages are handled, the temperature and humidity variations it is exposed to, state of roads and cargo containers, may affect the product's quality while being transported. Currently, Alfa Laval receives around 30 to 50 claims of product and packaging damages per year which leads to significant costs. In an increasingly competitive global market, companies must not only produce high quality products but they also have to safely deliver them in a cost efficient manner. The shipment of products to customers in good conditions, is a basic service that manufacturers are expected to provide for their customers. This will increase customers' satisfaction and intention of re-purchase, it will also save Alfa Laval GPHE reimbursement costs in case of damages.

1.3 **Problem description**

One challenge that Alfa Laval GPHE and many other companies are facing is related to packaging logistics within a global context. As a result of trends such as globalization, the complexity and length of the supply chains are constantly increasing (Aelker et al. 2013). When operating on a global scale, companies start to progressively lose control over their supply chains as more parties are involved. Consequently, companies are having less information available which make it difficult for them to identify the risks, quantify and mitigate them (Majta 2012). As a matter of fact, as the business grows, products are constantly being exported to new destinations. Depending on the product's destination, it will be handled, transported and stored in different ways and under various conditions. This raises concerns about low packaging performance in the new transport routes used to export products to customers in new destinations. In this case, low packaging performance designates the industrial package's inability to protect the product from potential damages in the new transport routes, as it was not designed for these conditions. One example of poor packaging performance is an under-packed packaging, or a packaging not providing humidity protection or protection from shocks/vibrations. Thus, allowing product damages or product quality deterioration which ultimately leads to customer dissatisfaction.

One of the main roles of packaging is to ensure that the product reaches the customer in good conditions without any damages (Natarajan et al. 2015). In order to ensure that this goal is continuously fulfilled, companies must review and upgrade their packaging systems on a periodical basis (Corner and Paine 2002). In addition, in order to upgrade the packaging systems and make them more protective, companies are required to have a good understanding of the foreseeable conditions that the product will encounter as it flows through the distribution system (Russell and Kipp 2006). Currently, Alfa Laval GPHE does not have a clear understanding about the various conditions involved in the different supply chains and the way these conditions affect both the industrial package and the packed product. This lack of information is even more critical in supply chains involving developing countries, which face challenges in regards to lack of established third party logistics organisations, poor road tracks, inefficient or unavailable handling facilities and equipment (Prater et al. 2009; Arvis et al. 2010; Rabiya and Edward 2016). Another concern is that, currently at Alfa Laval GPHE as in many other companies, the aspects related to packaging systems and logistics activities were considered separately, but the interaction between the two has rarely been taken into consideration. This raises concerns about the effectiveness of current packaging systems in the supply chains. It also raises the concern of inadequate packaging design decisions that can potentially lead to sub-optimization (Hellström and Saghir 2007).

Therefore, the first challenge is to identify the specific conditions of the different supply chains (e.g. climatic conditions and shock levels), the inherent risks and how they affect the industrial package. The second challenge is to identify the various factors influencing the risks in terms of occurrence and degree of damage they can caused. Then raises another challenge of making the right changes in the packaging designs in a way that optimizes the industrial packaging's performance across the different supply chains, in a cost efficient manner.

1.4 Purpose and goal

The purpose of this thesis is to understand what risks are involved in the transport activities in global contexts, which will provide Alfa Laval GPHE with data to make the right decisions regarding their packaging logistics operations in a global context. The results of this thesis will provide a better foundation for making decisions and trade-offs in order to efficiently and effectively enhance the industrial package's performance. Based on the current situation in the company, these are the questions that will be addressed by this thesis work:

-What are the supply chain conditions (e.g. temperature, humidity and shocks) which the product and the package are exposed to in the different transport routes starting from Lund towards Africa, Middle East, Asia, Northern and southern Europe?

-What are the types of damaging risks (e.g. mechanical shocks or corrosion) that the product and the industrial package may be subject to during transport?

-What are the risk factors affecting these risks' probability of occurrence and degree of damage they can cause?

-What improvements can be made to close the gap between the various supply chain requirements and the current packaging system?

1.5 Limitations

The first limitation of this project is related to the project timeline since the project had to be completed within a 20 weeks period. The second limitation relates to confidentiality, since there were restrictions when it comes to accessing some internal documents, as well as recording the conducted observations and interviews. The third limitation is related to the fact that Alfa Laval GPHE does not own the whole supply chain it uses to deliver the products to its customers. This created difficulties in terms of accessing data, conducting interviews and observations for instance at the facilities used by the 3rd party logistics operators. The fourth limitation relates to the fact that Alfa Laval GPHE ships its products using various transportation methods such as truck, ship, and airplane. However, in this project only truck and sea freights were studied. The fifth limitation was that the project involved sending products to few destinations that were selected to give an overall idea about their regional climatic and infrastructural characteristics, as well as the subsequent risks. However, the selection of only few destinations as references raises concerns about the accuracy of this thesis results and limits their applicability for other regions that were not part of this thesis work. Finally, the researchers were unable to find at what exact point or operation was the shock recorded inside the Alfa Laval facility. As a matter of fact, the interpretation of the recorded data regarding the product flow within the Alfa Laval factory, was based on the assumption that after fitting the sensor into the package in the packaging line, the package is directly moved to the storage area and then moved to the loading zone. However, this assumption may not be fully true, as it is possible that the package is first stored in a certain place and then moved again to be stored in another place. Thus, in the future, extended research can be conducted to pinpoint the exact operations.

2 METHODOLOGY

In this chapter, the general research approach adopted in this project will presented. In addition, the various research tools and their purpose in this project will be explained.

2.1 General approach

The researchers used an abductive research approach, in which theoretical knowledge was combined with quantitative and qualitative data collected through various methods to answer the research questions and provide suggestions for improvements (Kovács and Spens 2004). The researchers approached the topic in hand using systems thinking, which is a holistic approach used to analyze systems that are made of different interacting elements that affect each other and the system as a whole (Haines 2010). The figure 1 below illustrates the general project approach and Table 1 summarizes how the different research tools were used to answer the research questions. The use of systems thinking will be discussed further in section 2.2.

The researchers started the project by meetings that took place at Alfa Laval GPHE with the various project stakeholders, in order to understand the project background, to determine its purpose and goals, and finally to establish the scope of this thesis project. Next, literature reviews have been conducted in order to acquire a better understanding of the project focus area, its specifications and challenges. Literature reviews were also conducted to acquire knowledge about the research approaches, the data gathering methods and how to use them in this project. Then, data collections took place through various methods such as interviews, observations, examinations of internal documents as well as the usage of data loggers and GPS trackers. The purpose of using multiple data gathering methods was to gain a holistic view in a way that the data gathered from each of these methods will be complemented or explained by data obtained from other methods. For instance, the purpose of both interviews and observations was to get a deeper understanding of the various processes inside Alfa Laval GPHE. However, observations were conducted to identify the existence of process-inherent irregularities or aspects which may have not been mentioned during interviews. In addition, the internal documents were reviewed to get familiar with the components and properties of both the product and the industrial package. The internal documents were also used to identify what were the damages that occurred in the past, what was their causes and which ones occurred more frequently. Data loggers and GPS trackers were used since they enable a real time monitoring of humidity, temperature, shock and location. Therefore, they will reveal what kind of conditions the product and the industrial package are subject to during their flow from Alfa Laval factory to customers. The data loggers were also used to provide explanations to the damages that occurred outside the Alfa Laval GPHE facility. Finally, after analysing the collected data, the results have been compiled and reported in this master thesis. The steps of the methodology adopted in this project are clarified in details in this chapter.

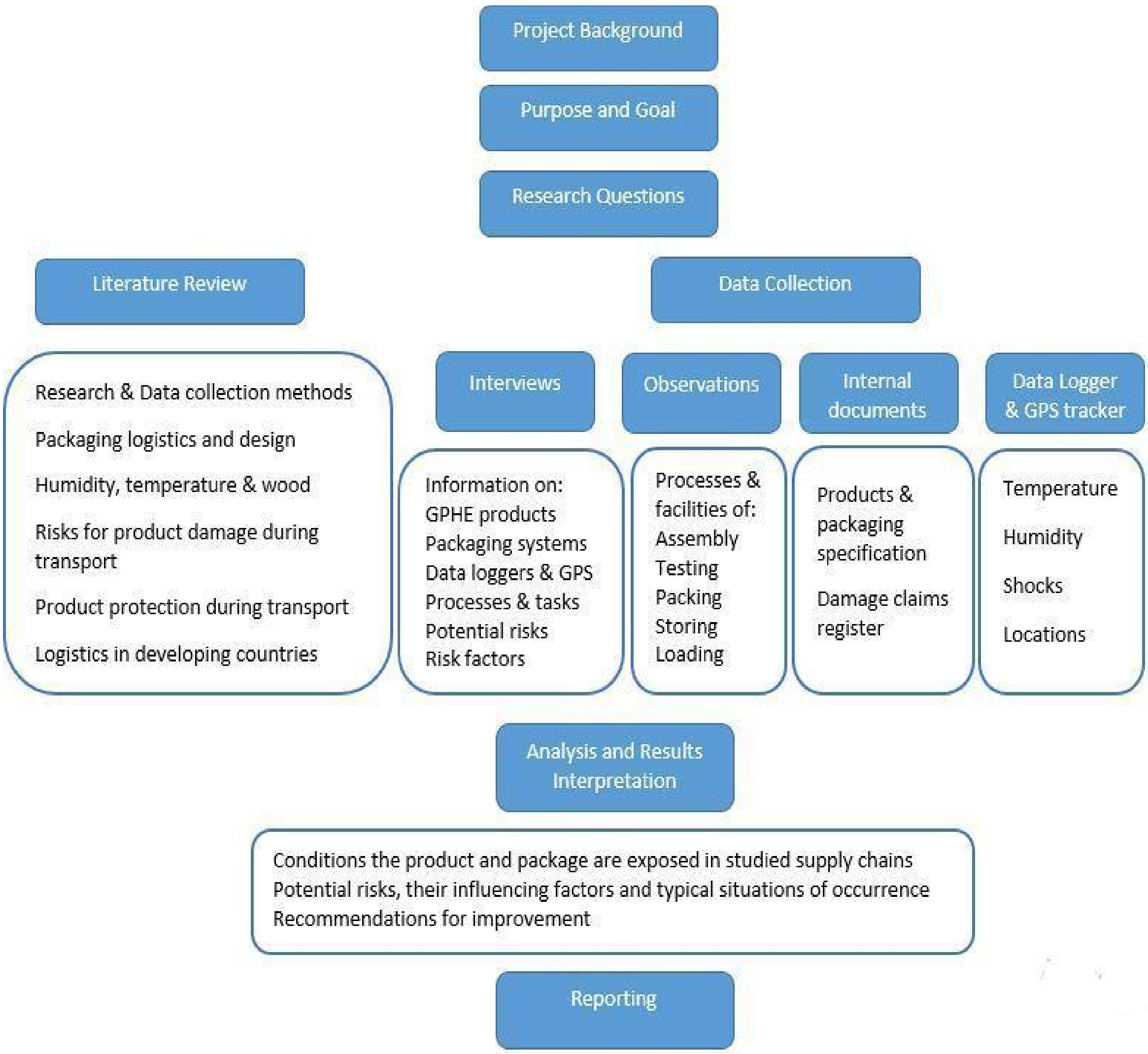

Figure 1 Overall project approach

Table 1 Research tools and their purpose in answering the research questions

Tools	**Purpose and usage in answering the research questions**
Data logger & GPS tracker	-Enables the monitoring of temperature, humidity and shock data at different locations throughout the supply chain -Enables the identification of the conditions that the product and the package are exposed to within Alfa Laval GPHE and during shipment throughout the supply chains.
Literature review	-Enables the identification of the potential risks and the different risk classification methods -Enables the identification of typical situations in which damages occur -Enables the identification of the product & package parameters, and the situational data that define the degree of damage caused -Clarifies the effect of humidity and temperature on wooden packaging -Clarifies the concept of packaging, the requirements of its design and its role within the supply chain -Provides ideas on how to improve the current state and provide higher protection for the product
Interviews	-Provides information on how to interpret the sensor data collected and check its reliability -Provides specifications of the product and its packaging, which enables the identification of both the conditions that can lead to damages and the different types of damage -Provides information about processes inside Alfa Laval, which enables the detection of process inherent risks that can lead to damages and the identification of their factors -Provides ideas on how to improve the current packaging and enable better protection for the product
Observations	-Provides straightforward explanations to sensor data collected inside Alfa Laval facility -Enables the researchers to make assumptions when interpreting sensor data collected inside Alfa Laval facility -Enables the detection of potential risks related to Alfa Laval's internal processes and facilities that can lead to damages and the identification of their factors -Provides ideas on how to the current packaging system works and helps in understanding its pros and cons
Internal documents	-Provides specifications of the product and its packaging, which enables the identification of both the conditions that can lead to damages and the different types of damages -Enables the identification of types of damages that have occurred during the delivery process in the past and explain their origin (factors). -Provides ideas on how to improve the current state and provide better protection for the product

2.2 Authors' contribution

This research project was done in a collaboration between two master students, Sadki. F, student at Oulu University and Mergin Singaraja. P, student at Lund University. The two master students have worked together to set the research questions and establish the research methodology to approach the project in hand. All the interviews and observations were done in the presence of the two researchers, while the literature review topics were divided. In order to clarify the contribution of each author, the thesis was considered to have 3 main goals, namely, identifying conditions of the studied supply chains, identifying potential risks for cargo damage and their influencing factors, and finally to make suggestions for improvement. The workload was divided in a way that on one hand, Mergin Singaraja. P focused on the first thesis goal which was to define the conditions of the studied supply chains. This involved extracting the shock, humidity, temperature, and location data from each of the 10 sensors used. Then analyzing the sensor data to identify potential similarities, differences and patterns throughout the various supply chains.

On the other hand, Sadki. F focused on the second thesis goal which was to identify the potential risks, their influencing factor and the typical situations in which they occur. This was done by combining the data collected from the sensors, interviews and observations with theoretical knowledge from literature about risks in transport, logistics in developing countries and the effect of humidity on wood and metals. This analysis resulted in the establishment of a risk-factor map, in which the risks were listed and classified according to their nature (e.g. Mechanical or chemical risks) and the risk factors were classified according to the elements they relate to (e.g. climate, communication, packaging system). The link between each risk, its influencing factors and the typical situations in which was also established in Table 14.

Finally, the researchers combined the results of their focus to achieve the third thesis goal which is to identify potential solutions to improve the current state and achieve a better cargo protection during transport. A total of nine improvement suggestions were identified then discussed and motivated in the end of the report. It is important to note that the two researchers assisted each other and worked closely together throughout the research project in order to yield high quality results that are harmonious, consistent and not contradictory.

2.3 **Systems thinking**

In order to effectively tackle the complexity of the project in hand, the research topic was approached from a systems perspective. The systems thinking was used in way that a set of parts are seen as part of a whole that serves a defined goal (Haines 2010). The studied system in this project is cargo shipment in which various parts are serving the goal of transporting a product to the customer, ideally without any damages or quality deterioration. This studied system involves many parts and organisations that all together contribute to either the success or failure of the overall mission. These system parts are the product, the packaging system, the forwarders involved and external factors such as climatic and infrastructure conditions. First, the product's influence on the safe delivery of cargo is determined by its characteristics, for instance, in terms of its component materials, fragility factor and surface finish. Second, the packaging system plays a major role in the success of the overall mission, as it defines the protection level that the product has against external elements which can cause damages. Moreover, the packaging system is also considered as the interface between the product, the forwarders and external conditions. Therefore, it can control the degree of influence the other system parts have on the success or failure of the overall mission. For instance, a package with high humidity protection will limit the influence of climatic conditions such as rainfall. Third, all the forwarders involved in the product packing and cargo shipment process will greatly influence the ability to deliver the product in good conditions. Concrete examples of this influence relate to the forwarders level of caution, as well as the methods, equipment and facilities they use to handle the cargo throughout the shipment journey. Finally, the external conditions such as the transport route's climate and infrastructure will have an effect on the safe shipment of cargo, the degree of influence will depend on the characteristics of the product and the packaging system used. In order to answer the research questions, the research must have a clear understanding of the system, it parts and how they interact with each other. To perform the required analysis, data about all the parts of the system will be collected using various methods explained in the sections below. The figure 2 below presents the studied cargo shipment system and its parts, and under each of the system parts was listed some examples of their influencing elements.

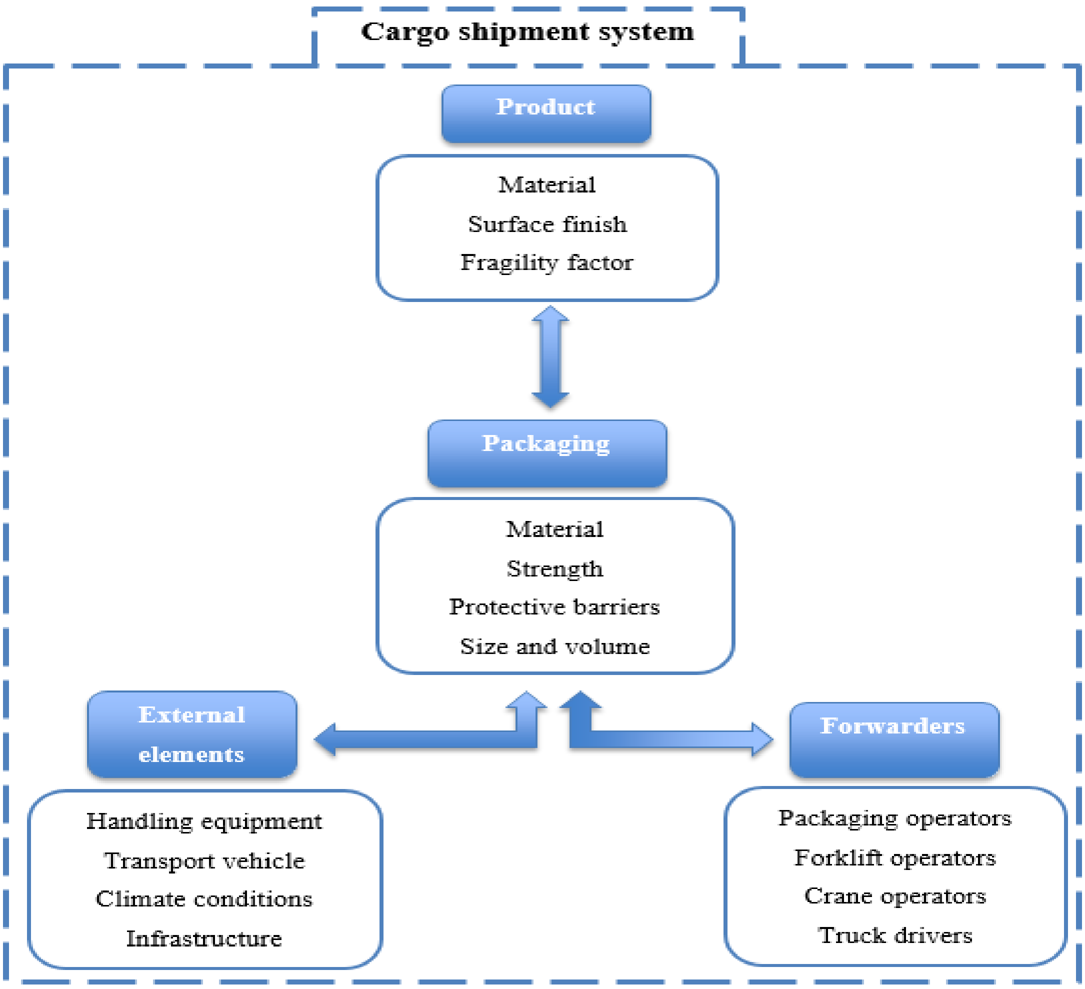

Figure 2 The studied system

2.4 Literature review

Literature review is an effective information gathering method which enables researchers to have access to a great amount of information within a given field and it is based on the revision of various sources such as research articles and books (Björklund and Paulsson 2014). In this project, the purpose of the literature reviews was mainly to acquire a ground understanding of the research topic in hand, properly interpret and explain the results found. The literature reviewed was related to packaging logistics and packaging design, the effect of humidity and temperature on the wood, risks in transport, achieving product protection during transport and transport logistics in developing countries.

The literature reviews were also used to find out what are the most suitable research tools and methodologies that can be used in this project. Literature has been reviewed throughout the project and was gathered from various sources such as online search engines, the university databases and library. The search strategy for the literature was to first identify the relevant concepts and keywords, then to choose data sources and proceed with running searches mainly through term combinations. The final step in the search strategy was reviewing and refining the search results (Monarsch University 2018). Noteworthy that as suggested by Patel and Tebelius (1987), aspects regarding information appropriateness, validity and objectiveness have been considered while conducting the literature reviews.

2.5 Qualitative Research

Qualitative research is a research strategy that highlights words rather than quantification during the collection and analysis of data (Bryman and Bell 2007). In this study, interviews, observations and examination of internal documents were conducted in order to have a deeper understanding of the product, the package, the various processes and to collect qualitative data.

2.5.1 Interviews

Brewerton and Millward (2001) state that interviews are susceptible to various biases and limitations. Therefore, in order to minimize these interview biases and achieve reliable results, the following precautions have been taken. There was a pair of personnel interviewed in each department. All interviews were conducted by the two researchers in order broaden the view of questioning. In addition, the interviews' topics focused mainly on the industrial packaging with respect to its performance and its risk.

Table 2 & 3 provide information about the personnel that took part in the interviews. Most of the interviewed personnel were working directly for Alfa Laval GPHE, the others were employees of third party logistics organisations (3PL) and the data logger product provider. The interview questions were framed to provide a better knowledge about the processes at Alfa Laval GPHE and to understand how the 3PL coordinates the cargo shipments with Alfa Laval GPHE. The interviews were recorded using laptops and paper notes. As presented in figure 2, the interviews conducted for this thesis report were either non-standardized or semi structured. There were also follow-up questions during the interview process which were made based upon the respondent answers in order to get further clarifications. Respondents were selected from different department that is from Packaging, Product R&D, Transportation and Packaging designer and every respondent were experienced personnel. The findings from the Interview will help the researchers to evaluate or confirm the findings made during the observations and helps in analysing the sensor data.

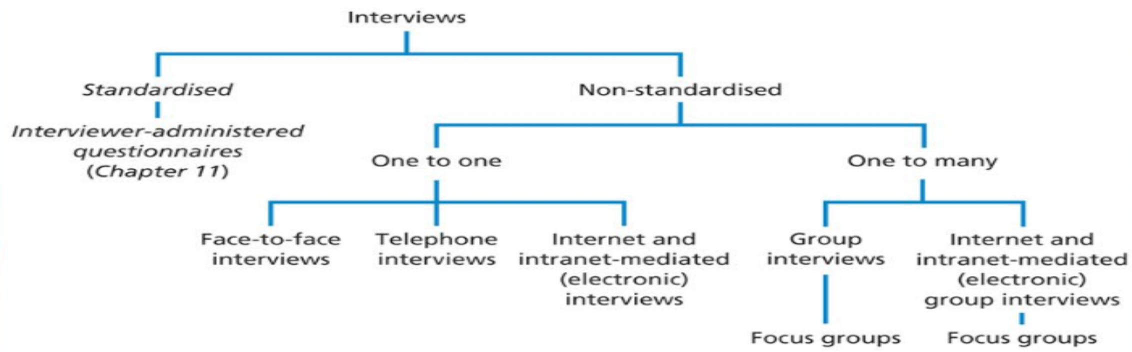

Figure 3 Types of Interview (Saunders et al. 2009)

Table 2. Interview personnel from Alfa Laval GPHE

Respondent	**Designation**	**Department**	**Interviewed Date**	**Types of Interview**
Christian Hansson	Operator	Testing & Packaging	March 15th	Face to Face
Stefan Malm	Team Leader	Assembly unit	March 15th	Face to Face
Peter Hansen	Internal Transportation	Transportation	March 15th	Face to Face
Joakim Krantz	Manager	R&D	March 15th	Face to Face

Table 3. External Interview personnel

Respondent	**Designation**	**Department**	**Date of Interview**	**Type of Interview**
Simon Bystrom	Development Engineer	Former Employer	March 3rd 2018	Call
X	Transportation	3PL (DSV)	March 2nd 2018	Email

2.5.1 2.5.2 Field observations

As defined by Angrosino (2007), observation is the activity of taking note of a phenomenon for scientific drives and may involve recording it for future reference. Field or on-site observations have been conducted throughout this thesis work starting from the early stages of the project. The goal of the observations made was to gather first hand data and as suggested by Brewerton and Millward (2001), for the researchers to familiarize themselves with the studied phenomena which in this case is the various processes, infrastructures and equipment used in the transport of industrial packages.

The researchers observed how the products are assembled at the production site and how they are packed using the various packaging systems. The process observations also included how and where the packages are stored and finally how they are loaded into the trucks. The data collected from the observations comprised field notes and pictures that were used as future references. As suggested by Marshall and Rossman (2006), the observation was based solely on "systematic noting and recording of events with no special effort to have a particular role in the setting". Noteworthy that in order to avoid the observers' bias, the observations took place independently by each of the 2 researchers, both under the supervision of Alfa Laval's personnel. The observations mainly took place at the Alfa Laval factory site in Lund, this was due to the fact that the company does not own the whole supply chain, as well as the restrictions regarding the project timeline and budget. Noteworthy that pictures and videos were not allowed to be recorded by the researchers due to the confidentiality restrictions at Alfa Laval GPHE. However, some picture was taken by the Alfa Laval GPHE personnel and then sent to the researchers.

2.5.3 Internal documents

Various internal documents of Alfa Laval GPHE have been reviewed during this project. This document comprises slide presentations providing information about the product and the packaging systems, such as their components, materials and technical specifications. One important internal documents were a compilation of some customer complaints regarding damaged products. The document determined the product type, its destination and suspected damage causes and it also contained visual illustration of the damages that occurred.

2.6 **Quantitative Research**

A quantitative research embodies results that are measurable and quantifiable (Björklund and Paulsson 2014). A quantitative approach is one in which the investigator employs strategies of inquiry such as experiments and surveys and collects data on predetermined instruments that yield statistical data (Creswell 2002). In this research, experiments were conducted by using sensors to collect numerical data about shock, temperature and humidity throughout various supply chains. The purpose of the collected quantitative data is to provide a deeper understanding about the supply chain conditions that the cargo is exposed to.

2.6.1 Data logger and GPS tracker (MOST sensor)

According to Alfa Laval GPHE there are around 30 to 50 damage claims every year related to products and packages which have been damaged during transportation. The percentage of damaged products is relatively small, however considering the high price of the single GPHE units, the cost of damages is quite significant. In order to find the cause of these incidents, the researchers decided to investigate the conditions that the product and its package are exposed to during transport, by installing data loggers that can measure Temperature, Pressure, Humidity and Vibration. The data logger is a device which helps in recording the data by directly storing it in the device or transferring it to a computer or mobile through internet or in this case data through GSM technology.

The selection of the MOST Mobile Sensor was done after conducting online research and contacting few sales people to inquire about the various types of data loggers. However, the cost and the additional features like in-built GSM technology for real time location monitoring, being Reusable, Rechargeable and providing a 100 days battery life acted as a decision factors for choosing MOST 1.0 (Figure 3). According to the MOST 1.0 specification sheet, it is water resistance, temperature can be measured from -20^{o}c to 55^{o}c which is a NIST traceable, for the relative humidity measurement working condition ranges from 0 to 100%. The shock reading is monitored with the technology 3-axis G sensor, which tracks the vibration created by every shock and its price is 50USD per piece. The product is relatively new to the market; however, it has been used by well-known companies to monitor or track their shipments. Once the product was bought from the supplier, a demo session took place with the presence of the 2 researchers. The demo session explained the usage of the MOST sensor and its online platform in which the collected data can be accessed.

Figure 4. MOST 1.0 Sensor

Figure 5. Sensor installed and fixed with tape in the packaging.

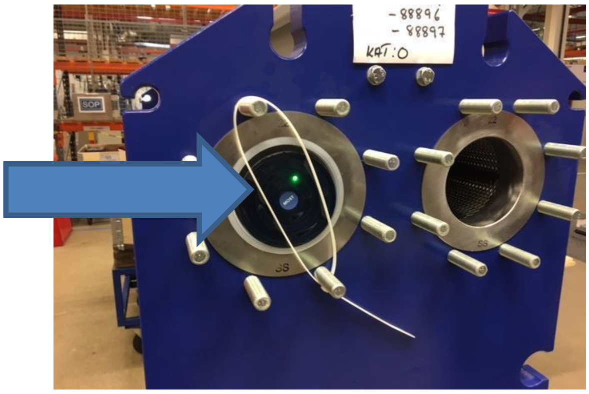

Figure 6. Sensor installed in the product itself

The Most 1.0 sensors were installed and tightly fixed in 2 ways, either on the wooden box inside the packaging (Figure 4) or in the second figure it was installed in the product itself (Figure 5). The installation was done in the packaging assembly line, before the product was fully packed. This was done to enable the monitoring to start at an early phase and thus researchers would be able to monitor the Vibration, Relative

Humidity, Temperature and Shock during the entire supply chain. The sensors were installed in different product types, using different packaging systems and sent to different destinations. The research plan was to select products of small and medium sizes, while the destinations were selected according to availability of customer orders and the time taken for each shipment to reach its destination, as the project timeline was limited. The selected cargo were destined to, Sweden (2 units), 2 Northern European countries, 2 Southern European countries, Middle East (1 unit), Asia (1 unit) and Africa.

Table 4. Sensor installation List

Shipment No	**Packaging**	**Destination**	**Transportation**	**Product**
Shipment A	Skid Base	Sweden (Nacka)	Truck Freight	AQ6
Shipment B	Skid Base	Sweden (Nacka)	Truck Freight	AQ4L
Shipment C	Plywood Box	Italy (Robbiate)	Truck Freight	M6
Shipment D	Plywood Box	Spain (Log Barrios)	Truck Freight	M10
Shipment E	Skid base	Germany (Augsburg)	Truck Freight	M10
Shipment F	Plywood box	Germany (Berlin)	Truck Freight	M15
Shipment G	Skid base	UAE (Dubai)	Sea Freight	AQ8
Shipment H	Wooden box	China (Shanghai)	Sea Freight	M10
Shipment I	Plywood box	Czech Republic (Moravske Budejovice)	Truck Freight	TL6

Shipment J	Wooden Box	South Africa (Kempton park)	Sea Freight	M15

The sensors were used to collect data in order to proceed with the quantitative analytical approach which helps the researchers to understand what conditions the current packaging system is exposed to in terms of temperature, relative humidity and shock. The collected data can also act as a motivation factor when suggesting recommendations and as a decision-making point or helps in future studies.

2.7 **Data analysis**

The various data collection methods used have generated a large amount of data. In order to efficiently and effectively use this data, the researchers used the following analysis procedures as suggested by Yin (2011).

The first procedure was compiling the data gathered independently by the two researchers during the conducted interviews, observations and internal documents reviews.

The second procedure was disassembling, in which the compiled data was sorted into different folders classified according to the topic the data relates to. The folder classifications were for instance, product, packaging system, packaging process, etc. The third procedure was reassembling, in which the sorted data was put into a matrix. The matrix had 2 axis, one axis for the data classifications used in the previous step (e.g. product, packaging systems) and the other axis had classifications according to the research question topics such as, supply chain conditions, potential risks, risks factors and suggestion for improvement. The goal of the matrix was to systematically establish connections between the gathered data and the research questions. The researchers established these connections in form of cause-effect relationships, to the greatest extent possible. The fourth procedure was interpreting, in which the existing connections found in the matrix results were combined with theoretical knowledge from literature and used to answer the research questions. The matrix established in step 3 was the foundation of the risk-factor map. The final procedure was concluding, in which he main findings were summarised and recommendations for improvement were suggested.

2.8 **Validity and reliability of the Analysis**

Validity and reliability are two principles that are traditionally used to evaluate the quality of research (Bryman and Bell 2007). Reliability deals with the ability of the research results to be repeatable for a following study and validity refers to the integrity of research outcomes (Bryman and Bell 2007). One of the methods used in this project was triangulation, which is a methodology used in order to increase the results validity. As stated by Bryman and Bell (2007), "triangulation technique helps in increasing the validity by collecting data from different sources". In this project, "rich" data was collected from different sources such as interviews, observations, documentations and websites. In addition, the validity of the research can be increased by formulating clear, impartial questions for interviews (Rönnholm 2006). Thus, the researchers formulated clear and impartial questions for the interviews. For example, the questions were asked in a way that prevents bias by focusing on getting a subjective description of the processes and packaging systems, instead of focusing on the role of the interviewee and his working performance. As suggested by Maxwell (2009), the comparison method was also used in this project to increase validity. For instance, the sensor results collected for the various supply chains were compared with each other and with theoretical data collected from various sources, in order to ensure the validity of the identified behaviours and patterns. This project has been accomplished by two researchers working as a team and as stated by Yin (2011) team work has a positive impact on research. This teamwork has reinforced the validity and reliability of the study since it helped in gathering more data and reducing bias during the interviews and observations. Team work has also enabled the comparison of data gathered independently by each of the researchers in order to identify potential mistakes.

3 LITERATURE REVIEW

In this this chapter, the main theoretical concepts used in this thesis project will be defined.

The first topic addressed in this chapter relates to packaging logistics, it will be discussed in order to provide a general understanding of packaging, logistics and packaging involvement in logistics. Second, theories related to factors influencing packaging design will be discussed to provide a general explanation of the packaging design process and its requirements. Third, literature regarding the effect of temperature and humidity on wood will be discussed in order to understand how the package reacts to these parameters and how it can be damaged when exposed to inadequate levels of temperature and humidity. Fourth, theoretical knowledge related to risks in transport will be discussed to provide indications of the various types of transport inherent risks and the different ways in which they can be classified. Fifth, theories related to how organisations can achieve effective product protection during transport will be presented. Finally, literature about transport logistics in developing countries will be presented giving an overview of the obstacles that can be met when operating in developing countries.

3.1 Packaging Logistics

First, regarding the concept of packaging, Natarajan et al. (2015) states that "Packaging is a coordinated system of preparing goods for transport, distribution, storage, retailing and end use. It aims at ensuring the safe delivery of the product in good conditions at a minimal cost". Lockamy III (1995) adds that "packaging has 6 primary functions which are Containment, Protection, Apportionment, Unitization, Convenience and Communication". The role of packaging is expanding due to the increased logistics costs, improved packaging technology and enhanced environmental regulation (Lockamy III 1995). As a matter of fact, packaging is nowadays considered as a central component in logistics, as it follows the product from the point of filling to the point of consumption (Molina Besch and Pålsson 2015). In this research study, the main packaging criteria relates to the protective ability against shocks, vibrations, temperature and humidity. However, in order to avoid sub-optimization other aspects must also be considered such as achieving efficiency during handling and transport.

Second, regarding the concept of logistics, the council of Logistics Management (2006) defines it as “the process of planning, implementing and controlling the efficient, effective flow and storage of goods, services and related information from point of origin to point of consumption for the purpose of meeting the customer requirement”.

Finally, the concept of “packaging logistics” was found to have fairly less research articles. However, it is safe to assume that it is the combination of packaging and logistics. According to Saghir (2002), packaging logistics can be defined as “The process of planning, implementing and controlling the coordinated packaging system of preparing goods for safe, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal and related information combined with maximizing consumer value, sales and hence profit.”

3.2 **Factors influencing packaging design**

In order to have a package that effectively achieves its various roles, the packaging design process must take into consideration the influencing factors such as the packed product, the distribution environment, as well as the legal and customer requirements. These factors that influence the packaging design, varies in importance depending on the type of package and its purpose (Natarajan et al. 2015). The type of package used in this project is an industrial packaging and the focus is on the logistical aspect, mainly in terms of maximising product protection. Despite the fact that product protection is the main focus in this project, as stated earlier, avoiding sub-optimization in packaging design requires a holistic approach that takes into consideration other aspects such as efficiency during handling and transport.

Regarding logistical efficiency, Chen et al (2006) states that applying a logistics-oriented design can result in much more efficient processing in terms of handling, lifting and loading/unloading activities. Hellström and Nilsson (2011) adds that an integrated design approach that considers the packaging, the product and logistics is a driver for eco-efficient supply chains. In addition, applying such integrated design approach can increases supply chain integration. Thus, achieving a state in which the different functional areas and parts of a supply chain align their objectives and integrate resources to deliver the highest value to the customer (Ballou et al. 2000).

Regarding protection through packaging design, Garcia (2008) states that an important step in packaging design is the identification and understanding of design requirements from aspects such as logistics. There are many parameters linked to logistic activities that must be considered during packaging design. Azzi et al (2012) mentions the following "temperature, humidity, air (pressure, speed), water (i.e. rain, wetness, other sources), radiation (solar, heat), chemically active substances, mechanically active substances (e.g. dust, sand), flora and fauna (microorganisms, rodents, insects, etc.), vibration (caused by transit, handling, conveying, etc.), shocks, fall, acceleration, load, miscellaneous and electrostatic charging,". Finally, packaging design requires conducting various tests to evaluate the package's performance and optimise it if necessary. These tests include, drop and shock tests, compression tests, frequency, resonance and random vibration test as well as atmospheric conditioning (Goodwin and Young 2010).

3.3 **Humidity and Temperature effect on wood**

In this section, the researchers will discuss how humidity and temperature conditions have an impact on the packaging, in which wood is the main component. As a matter of fact, there are 2 packaging systems used by Alfa Laval GPHE, which are ocean packaging and skidbase packaging. Both packaging types can be made of either wood, plywood or a combination of the two wood types.

Relative humidity (RH) is the ratio of vapour pressure of water in the air, to that in air saturated with water vapour and it is often expressed as a percentage (Britannica 2018). Regarding RH's effect on wood, Wengert (2013) states that "an approximate 0.5 to 1 percent size change in wood is expected with every 1 percent change in wood moisture content. This wood moisture content change can happen when RH in the air changes about 5 percent". RLC engineering (2010) states that the wood moisture content depends on the air's RH and as it increases, so does the moisture content of any wood exposed to the air. Moreover, when wood is exposed to air with a RH of about 90%, the probability of the growth of moulds and other parasites increases. Regarding temperature's effect on wood, Wengert (2013) states that temperature alone doesn't have any effect on wood when the relative humidity is constant.

All in all, the exposure of wood to high humidity leads to changes in its consistency and favours the growth of microorganisms (e.g. fungi, moulds and bacteria) that causes bio deterioration and loss of strength.

3.4 Risks in transport

Every packed product that is being transported is exposed to some kind of risk(s). However, the types of risks, their probability of occurrence and intensity vary depending on different factors. These defining factors include for example the product and packaging designs, the transportation mode, the climatic conditions and the infrastructure of the transport route used. A concrete example would be the risk of damaging vibrations encountered during transportation, which are affected by road roughness, traveling distance and velocity, as well as the properties of the transport vehicle such as the type of suspension (Vursavus and Ozguven 2004). In addition, the type of container used and the load configuration are also influencing factors, it was proven that damages are more frequent in lightly loaded vehicles in comparison to heavily loaded ones (Hones et al. 1991).

According to Corner and Paine (2002), transport risks can be classified in different ways, such as mechanical, climatic and biological risks, which is a classification based on the nature of the risk. On the other hand, risks can also be classified according to the processes in which they may occur, such as risks of warehousing, risks of movement and risks of loading and unloading. In case of a risk classification by nature, mechanical risks could, for instance, include crushing forces, impacts and vibrations. The climatic risks may comprise for instance, inadequate temperature, humidity and air pollution. Another risk category is “miscellaneous risks” which refers to “other risks”, the risks included under this classification vary based on what is considered as miscellaneous for the organisations conducting the classifications.

It is important to note that the presence of the risks will not necessarily cause significant damage, as a matter of fact, considerable damages will only occur after the exposure to the risk for a certain period, frequency or exceeding a certain parameter (Natarajan et al. 2015). For instance, the damage caused by drops is influenced by the drop height and the impacted surface properties. Moreover, the damaging effect of vibration depends on its frequency and the duration of exposure (Goodwin and Young 2010). The table (5) lists some potential mechanical, climatic and biological risks and compiles the properties determining whether a risk will lead to a significant damage (Natarajan et al. 2015; Jorgenson 2015; Corner and Paine 2002; Goodwin and Young 2010, Mendoza and Corvo 2000, Vursavus and Ozguven 2004, Russell and Kipp 2006, Kubiak et al. 2009).

Table 5 Potential risks and the situational properties affecting the degree of damage

Risks leading to damage	Properties affecting the degree of damage	Source
Shocks **(Drops and impacts)**	Height of fall, position and direction of impact, Frequency of drops, Impact velocity, characteristics of the impacted surface or nature of the impacting object	Corner and Paine 2002 Natarajan et al. 2015 Goodwin and Young 2010 Jorgenson 2015
Crushing & compression **Bending & deformations**	Origin of the force (stacking, strapping, nets) Stack height and weight ,Material of straps and slings	Corner and Paine 2002 Natarajan et al. 2015 Goodwin and Young 2010
Vibration	Amplitude, acceleration, frequency, continuous or periodical, presence of stacking loads or side loads,	Corner and Paine 2002 Natarajan et al. 2015 Goodwin and Young 2010 Jorgenson 2015 Vursavus and Ozguven 2004
Abrasion & surface markings **Puncturing, tearing & proliferation**	Nature of abrasive element (e.g. sand particles) or abrasive action (e.g. rubbing, erosion) Contact force or pressure Difference of surface hardness in contact areas	Corner and Paine 2002 Kubiak et al. 2009
Corrosion & material degradation	Atmospheric conditioning (e.g. Moisture, relative humidity and temperature variations) Duration of exposure	Corner and Paine 2002 Natarajan et al. 2015 Mendoza and Corvo 2000 Russell and Kipp 2006
Biodeterioration (e.g. wood decay)	Atmospheric conditioning (e.g. Moisture, relative humidity and temperature variations)Duration of exposure	Corner and Paine 2002 Natarajan et al. 2015 Russell and Kipp 2006

3.5 **Product protection during transport**

Every company that sells products must ensure that the purchased items reach the customer in optimal conditions and in a cost-efficient manner. In order to maintain the product quality while it is being transported and protect it from potential hazards, Hilton (1994) states that it is necessary to have a clear understanding of the nature of the product, the distribution chain and the components that constitute the distribution chain. This was confirmed by Russell and Kipp (2006), who stated that in order to develop protective packages, packaging designers are required to have a good understanding of the risks that the product may potentially encounter as it flows through the distribution system.

On a practical level, Corner and Paine (2002) state that if companies want to protect their products while being transported to the customers, they must conduct two preliminary assessments. These assessments require data that can be distinguished into two types, the first is information related solely to the product such as the product characteristics and the ways it can be damaged, as well as its relationship with the packaging system. The second type of information required, is related to the transport conditions and the hazards that can potentially be met while the product is being moved.

In the first assessment phase, the product characteristics must be defined in terms of its nature, size, shape, material properties, strengths and weaknesses. Then we must identify the risk factors that can cause damage to the product and its package. If possible, it is recommended to quantify these risk factors in terms of defining their limits, which if exceeded, would cause product damages. The information about the product and its components characteristics comes mainly from the product manufacturer. The last step of the product assessment, is evaluating the relationship and compatibility between the product and its packaging system.

In the second assessment phase, we must gather information about the transport modes that will be used, the climatic conditions during transport and storage, and finally the handling methods and tools used by the forwarders along the supply chain. There are four different methods that can be used to define the conditions that a product will be subject to during shipment. They are namely, literature review, observations, examination of damage claims and direct measurement (Russell and Kipp 2006).

Conducting these 2 assessments is very important, as the climatic conditions, means of transportation and handling methods can't not easily be altered along the supply chain. The only component that can be modified to protect the products shipped is the packaging system (Idah et al. 2012). Therefore, conducting these 2 assessments, enables to design or optimize the packaging system in a way that it is well adapted to the transport conditions and can effectively protect the product.

3.6 **Transport logistics in developing countries**

In recent years Alfa Laval GPHE increased its product export to developing countries. However, when designing the packaging systems currently used, conditions in these countries have not been taken into consideration. That is why the researchers are addressing this topic, to acquire a better insight of the characteristics of such regions. The transport logistics constraints blocking developing countries from accessing international markets, are the same constraints that the manufacturers from developed countries face when exporting their products to developing regions. These logistical constraints relate to challenges that freight forwarders face in regards to poor road and rail infrastructure, inefficient port and handling facilities (Arvis et al. 2010; Rabiya and Edward 2016). In addition, well established third party logistics organization are not widely available in developing countries. Therefore, it is a common practice to hire independent truck drivers and temporary workers which raises concerns about risks related to rough and careless handling (Prater et al. 2009). In addition, cheap labour costs, unavailability of handling equipment (e.g. forklifts) and facilities (e.g. docking station) makes manual handling extensively used in developing countries. The desire to maximize the space efficiency during transportation and storage leads to packages being stacked on top of each other, in way that exceeds the stacking height and load limits (Sohrabpour et al. 2012).

All in all, the previously cited characteristics of transport logistics in developing countries, limits the efficiency of cargo flow in terms of speed, reliability and cost (Tseng et al. 2005; Faye et al. 2004). In addition, these characteristics increase the risks of product damage or damage quality deterioration during transport, handling and storage. This consequently puts multiple requirements on the packages such as having a great compressive strength and being able to withstand rough and manual handling (Sohrabpour et al. 2012).

4 EMPIRICAL DESCRIPTION

In this chapter the product and the packaging systems will be described. Then an end-to-end map will be presented, describing the main supply chain processes with a focus on the packaging process. Finally, the shock, humidity and temperature data gathered from the sensors used in the 10 shipments will be presented.

The topics discussed in the empirical description were selected according to the recommendations made by Corner and Paine (2002) on how to achieve cargo protection during shipment. The first suggested step is a product assessment to understand the characteristics of the product in hand (e.g. size) this will be done in the first section of this chapter. Another part of the suggested product assessment, is understanding the product-packaging relationship, this was done in section 4.2 that also describes the properties and functions of the current packaging system. The second suggested assessment was to get a deeper understanding of the supply chain conditions. This was done by establishing the end-to-end map (section 4.3), with a focus on the packaging process (section 4.4) and using sensors to collect data for numerical description of supply chain conditions (section 4.5).

4.1 **Product Characteristics**

There are three different categories of industrial product types available the Alfa Laval GPHE portfolio. These categories are based on size, namely, Small, Medium and Large. The product types chosen for the thesis study were small and medium size products. The studied GPHE units were AQ6, AQ4L, M6, M10, M15, AQ8, M10, TL6, M15, and all the products are Gasketed Heat Plate Exchangers. The reason for selecting these products are due to their availability for shipment during the research time period. In table 6 the dimension of the products can be found.

Table 6. Product Dimensions Measurement in inches

Product name	Product size	Height	Width
AQ6	Medium	76 ½	(25 ½"
AQ4L	Medium	75.8/78	18.9
M6	Small	36.2”	12.6”
M10	Small	42.7”	18.5”
M15	Medium	76.4”	24.0”
AQ8	Medium	84 ½"	30 11/16"
M10	Small	42.7”	18.5”
TL6	Small	49.8”	12.6”
M15	Medium	76.4”	25.6”

4.2 Description of the packaging system

There are 2 types of packaging systems used by Alfa Laval GPHE, which are skidbase packaging and ocean packaging.

The skidbase packaging shown in figure 6 is constituted of a pallet that is specifically designed for Alfa Laval GPHE products and does not follow the EU pallet standard. The skidbase form, dimensions and strength depends on the product that will be mounted on it.

Figure 7. Skidbase packaging system

The skidbase is made either of treated or untreated wood and this depends on the product destination. While the skidbase packages made of untreated wood are mainly used for shipments within Sweden, the treated-wood packages are used for export outside of Sweden and are required to be in compliance with international shipment regulations. On one hand, the wood treatment is conducted to protect the wood from infestation and detrimental organisms such as pests and insects. On the other hand, the treatment also prevents the detrimental organisms from spreading into the environment of the product destination. However, the standard skidbase packaging provides a transport function solely and does not offer any protection from humidity or rough handling. It is noteworthy that in other Alfa Laval production facilities (e.g. china) the products are wrapped with a VCI plastic material that provides protection from humidity as seen in figure 7. This procedure is occasionally done in Lund, when requested by the client.

Figure 8. Skid base packaging with VCI humidity protection

The Ocean packaging shown in figure 8, has the shape of a case which is constituted of a skidbase, 4 side ends and a lid used on the top. The ocean packages are sometimes equipped with exposed eye or dog bones that are used to enable a smoother lifting of heavy products by cranes (Figure 9). The ocean packages are tailor-made specifically for the different Alfa Laval GPHE products. The material used to make the ocean packages is either wood, plywood or a combination of both. This choice is based on many factors such as shipment regulations and local purchasing strategy. In Sweden for instance, wood is considered to be cheaper than plywood, while in China plywood is considered cheaper. Consequently, the different Alfa Laval production sites will use different materials for their industrial packages. As its name entitles, ocean packages are used for products that will be shipped by sea. However, not all product shipped by sea are packed in ocean packages, this aspect will be discussed later in this report in section dealing with potential transport risks.

Wood Plywood

Figure 9. Ocean packaging

Figure 10. Ocean packaging with dog bones

Finally, it should be mentioned that the components used in the industrial packaging such as wood, bolts and straps are not made by Alfa Laval but purchased from various suppliers.

4.3 **End-to-end process map**

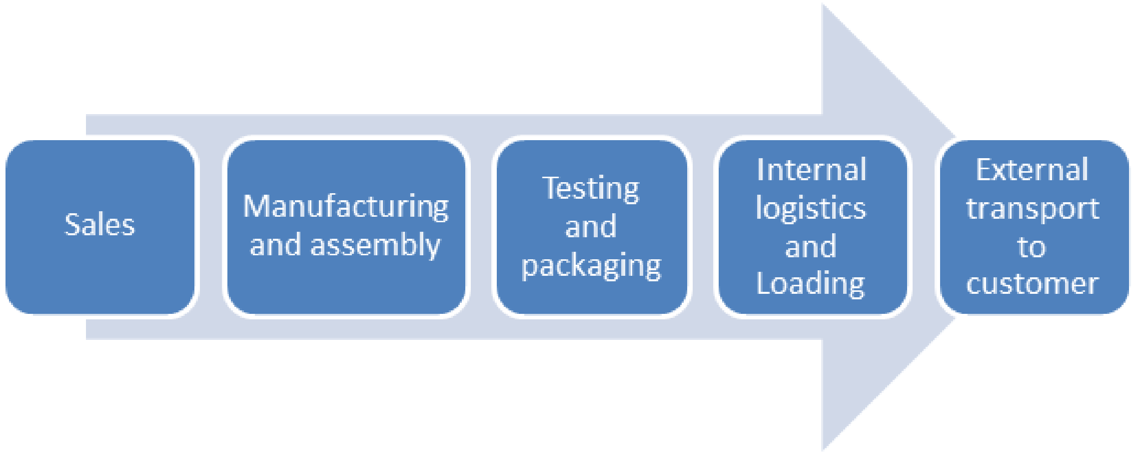

Figure 11. End-to-end supply chain process map

The figure 10 represents a short overall description of the business process at Alfa Laval GPHE and involves the functions that are directly related to packaging logistics. The business process first starts by the sales system in which the sales team is in contact with the prospective clients in order to assess their requirements and define the suitable product configuration. During the sales process, the various packaging solutions, their respective benefits and costs are discussed. However, the final decision regarding which product packaging system to be used is usually made by the customer. It is important to note that the customer decision is not always based on which package is the most suitable for the transport journey but often on the package cost.

The product is then configured by the sales team according to the customer specification and a manufacturing order is established. Most of the GPHE production process is done at the Alfa Laval factory, with some parts being outsourced to different suppliers. Once all the components are available, they are assembled together in the assembly lines resulting in the finished product. The GPHE units are then transferred to the testing zone in which they undergo a hydrostatic pressure test to ensure there is no leakage or product defects. If any defects are detected, the product is disassembled and fixed, otherwise the product is packed using the selected packaging system. The packaging process will be discussed thoroughly in the section 4 below.

The internal logistics function is responsible for transporting the packed GPHE units from the packaging zone to the warehouses, outdoor storage and loading zones. The internal logistics function is also responsible for loading the industrial packages into the truck beds. The loading of cargo into freight containers is done with the assistance of the external transporter. The communication between the internal logistics operators (e.g. forklift drivers) and the external transporter (e.g. truck driver) is not always effective due to language barrier and relies frequently on hand gestures.

Once the industrial package is loaded on the truck bed, the transporter is responsible for the safe handling, shipping and delivery of the package to the customer. The external transport is either organized by a 3rd party logistics organization hired by Alfa Laval GPHE or by the customers themselves which is referred to as self-pick up. The transporter manages the space utilization of the cargo container and must ensure that the cargo is not moving, tipping over or impacted during transport. Therefore, the transporter has the responsibility of effectively lashing and strapping the cargo into the freight container. It is important to note that product and package damages have occurred as a result of transported cargo not being well secured on the freight container or being impacted by other packages.

4.4 **Packaging process**

After conducting the pressure test, and in order to avoid product deterioration during transport, protections are put into the plate heat exchangers' nozzles and an anti-corrosion liquid is sprayed into the various bolts, nuts and washers. The GPHE units are then lifted from the ground by the use of cranes, the operator guides the unit moving it from the testing zone and places it safely on the skidbase. The orientation in which the GPHE units are placed on the pallets depends on their size class (small, medium or big) and length. For instance, in the case of medium size products, the units with a length smaller or equal to 1800mm are first rotated, placed laying on the floor and then lifted again to be positioned laying to the side on the skidbase as shown in figure 11. In order to keep the product anchored to the package base during the transport, the units are strapped to the skidbase using 2 Signode-Tenax® high performance polyester strapping. Noteworthy that similarly to the product orientation, the number of strappings used also depends on the product size and length.

Figure 12. Skidbase packaging with product laying on the side

On the other hand, the medium GPHE units whose length is over than 1800mm are lifted by the crane from the testing zone and placed standing vertically on the skidbase as shown in figure 12. The standing units are strapped using 2 high tensile strength and low elongation steel straps. Since the standing units are relatively big, they require more support to ensure they remain anchored to the package base during transport. Consequently, they are fixed to the skidbase by the GPHE feet through the use of nylon bolts and lock nuts.

Figure 13. Skidbase packaging with standing product

The previous packaging process description is valid for both skidbase and ocean packaging systems. The main difference is that in the ocean packaging, the 4 sides and upper lid are added and fixed to the package base forming a case (figure 13). In addition, in the ocean packaging another activity takes place which is the marking of the centre of gravity on the packaging. The marking of the units centre of gravity is done in order to enable proper handling of the package by the other handles down the supply chain that are not familiar with the product. As the ocean packaging fully covers the product, if the centre of gravity has not been marked on the package, this may lead to the packaging being dropped during handling and damaged.

Finally it should be mentioned that there are various teams that are responsible for packing different product types. Some procedures of the packaging process are conducted differently by the different packaging teams. This matter will be discussed more in the following section 5.2 of this report dealing with potential risks.

Figure 14. Ocean packaging with standing product (semi-packed)

4.5 **Sensor data description**

In this research study, a total number of ten sensors were brought and installed in the packaging or directly on the product in order to monitor the supply chain conditions such as Temperature, Relative Humidity, Shock or Vibration. Through the use of data loggers, researchers can track and trace the package flow and the stops made during the transportation. The researchers can also pinpoint if there were any irregularities in the supply chain condition such as the exposure to high humidity or high shock levels. The data loggers also enable the identification of the cause of such conditions, in terms of whether it happened during the flow of packaging (while on the truck or ships) or during any logistic activities such as storing, loading or unloading. As previously mentioned, the MOST 1.0 sensors used are able to monitor temperature ranges from -50 to 100, Relative Humidity range from 0 to 100% and the threshold for shock detections was set to 5g force.

The conditions such as Temperature, RH, and Shock are monitored because of the impact they can have on both the product and the packaging, such as corrosion, stress cracks.

The shock parameter was monitored according to the G force, which means a force acting on the body or object due to result of acceleration or gravity. For example, a 20-pound object undergoing a **g-force** of 5g experiences 100 pounds of **force**.
Force of Impact

$$F_i = \frac{Wa}{g} = WG$$

Where

- **F-** Force of impact
- **W**- Object weight
- **G**- g force

Noteworthy that if the shock force is higher than the safety stress of the wood then the failure of the packaging is eminent.

The Relative humidity parameter was also monitored, it refers to the ratio of amount of water vapour present in the air to the greatest amount possible at the same temperature. The RH parameter was monitored due the weakness of the current wood packaging which is its ability to absorb the moisture in the air and if the relative humidity in the air increases the moisture content in the wood increases. The additional water will cause the material to swell unless it is constrained. All cellulosic material such wood and paper may undergo considerable dimensional changes or if constrained may build up dangerous stress which lead to sudden failure. In certain conditions warping also occurs in wooden packaging (Thomson 2014). Thus maintaining low RH is necessary to avoid damages or deterioration of the product and the packaging. More specifically, when relative humidity is above 70%, the wood has excess moisture content and it can lead to decay and moulds can be formed.

Description of conditions at different supply chain process

The Sensors were fitted to the packaging in the assembly line, so that the data can be collected once the package starts moving along the supply chain. The graphs below are a visual representation of the values recorded at various points along different supply chains. The data presented in the graphs covers the whole supply chain, starting from the packaging assembly line, moving to the storage area, loading to the truck, transportation along the various routes, unloading at the destination or unloading at the dock or check point for change of transportation. The researchers identified the minimum and maximum values recorded for each parameter in the different supply chains and summarised the findings in Table 7.

Table 7. Data Collected from Sensor for the entire trip

Destination	**Temperature ^0C**		**RH (%)**		**Shock (g)**	
	Min	Max	Mini	Max	Min	Max
Czech republic	1	18	21	94	0.87	13.07
Spain	2	23.9	19.8	85.7	0	13.25
Italy	-0.2	24.9	19.6	89.2	0.26	13.14
Nacka 1	-9.2	21.7	19.7	100	0.93	9.45
Nacka 2	-5	22	11.9	93.3	0.89	12.77
Germany	1.1	23.8	76.4	92.7	0.02	12.24
Spain 2	1.8	22.2	22.6	93	0	13.08
UAE	-6.07	37.6	21	100	0	13.08
China	-3.6	29.7	14.4	79.5	0.76	12.71

South Africa	-6.1	27	13.8	93.8	0.77	12.84

Graphs have been created to present the recorded data of temperature, humidity and shock with the left hand axis or primary axis showing the range for the humidity and the right-hand axis or secondary axis showing range for the shock.

For the package sent from Lund to Nacka 1 (Figure 14), there were no notable shocks recorded during the transportation period. It can be assumed that this is due to the good quality of infrastructures (e.g. road tracks) in Sweden. However, there were notable shocks observed when the product was still inside the Alfa Laval facility in Lund. The highest shocks recorded had a magnitude of 9.45g and 7.44g which have been measured on 28th February. By looking at the date, we can assume that the shock most probably happened during the operation of moving the product from the packaging assembly line to the storage area. To make this reading more reliable it can be noted that the same conditions have been recorded by a sensor fitted in another package destined to Nacka2. In the second package, notable shocks with a magnitude up to 10.59g have been recorded during the time period where the product was moved from the assembly line to the storage area. For the humidity, it can be noted that it was constantly high during the transportation and had high range of humidity between 60-90% from the 2nd of March to 6th of March. It can be assumed that this was the time period where the product was stored in the open storage at the Alfa Laval facility. The same conditions were recorded for the second package which was sent to Nacka 2 (Figure 15).

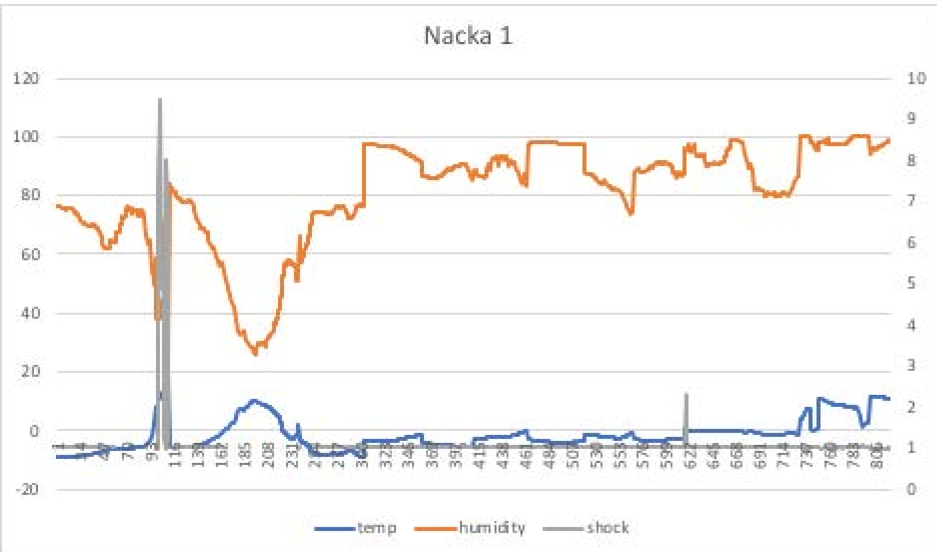

Figure 15. Sensor data from Lund to Nacka 1 (Sweden)

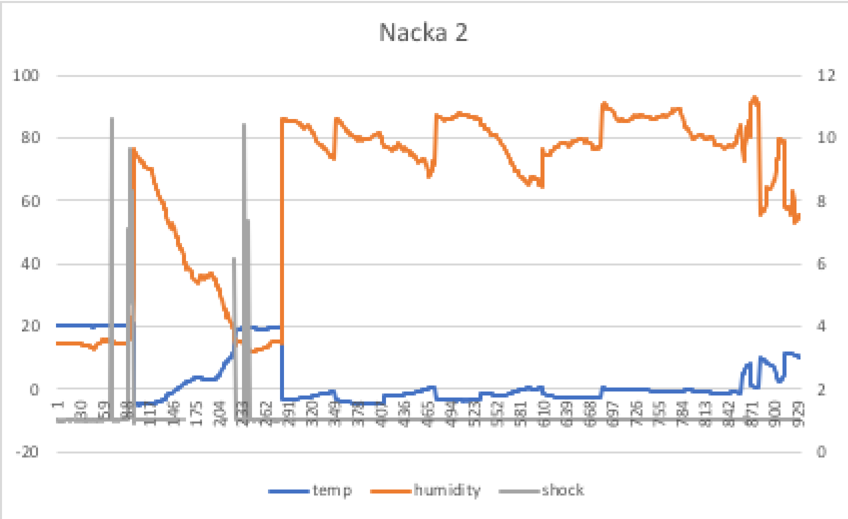

Figure 16. Sensor data from Lund to Nacka 2 (Sweden)

The package sent to Spain 2 (Figure 17) also had the similar experience where high shock values up to 13.14g have been recorded during the internal operations at Alfa Laval GPHE. As a matter of fact, a series of shocks have been recorded on 5th March which was the time period where the product would have been moved within the assembly line and then to the storage area. In addition, during the external transportation there were a series of shocks up to 13.25g measured and it happened while the product was on the truck. To validate this recording, similar recordings where noted in a sensor which was fixed to another package send to Spain 1 (Figure 16). Humidity was moderate during the time period in which the product was at the Alfa Laval facility and it gradually increased once the transportation begun and the humidity range was 40-60%.

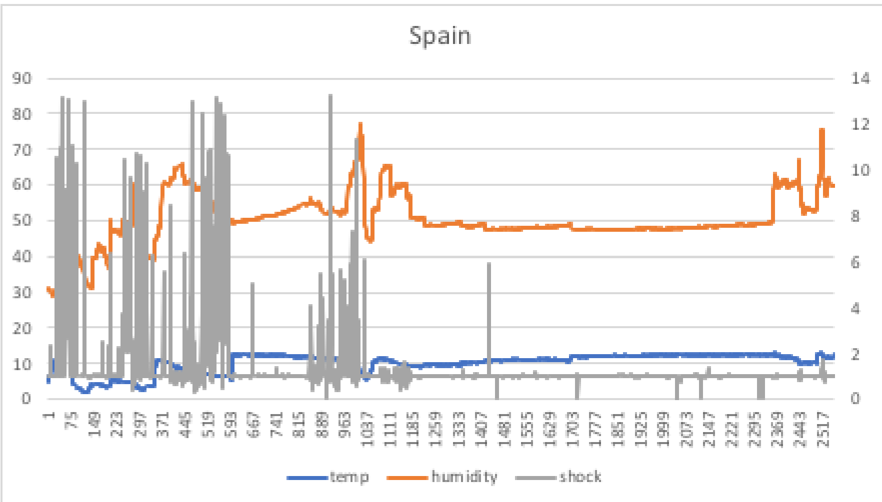

Figure 17. Sensor data from Lund to Spain

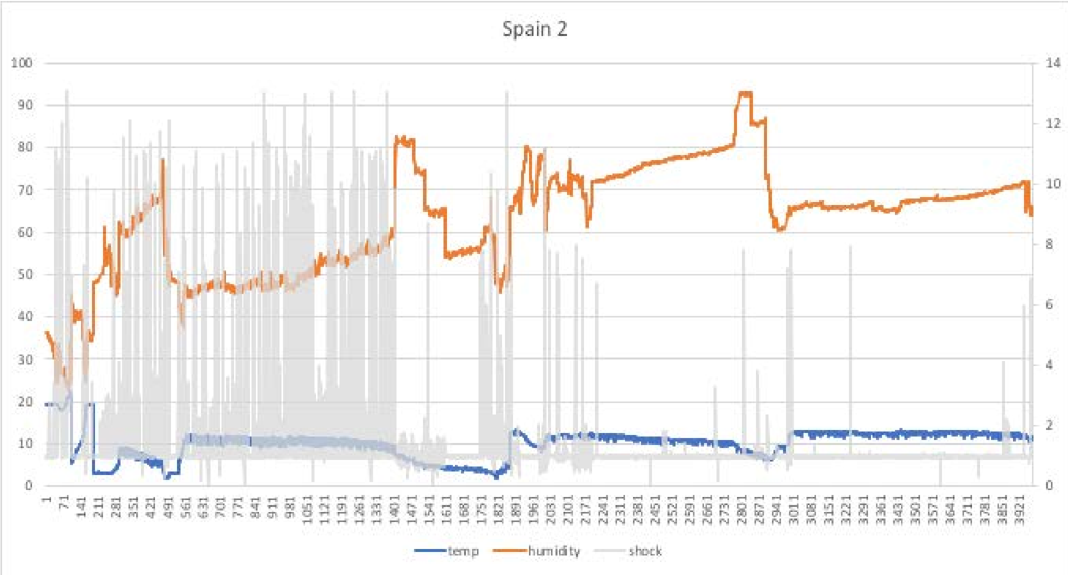

Figure 18. Sensor data from Lund to Spain 2 (Puertonallo)

For the package sent to Italy (figure 18) it can be noticed that there was a shock of 12.8g that was recorded within the Alfa Laval facility on the 7th of March. It can be assumed that this occurred when the product was moved from the storage to the truck for loading or was moved within the storage area. In addition, high shocks were observed during the delivery time frame. The highest shock had a magnitude of 13.14g and by looking at the GPS tracker, it can be assumed that it happened during the unloading of product at the customer's facility. For this package, humidity within Alfa Laval was not high, this may be due the fact that it was stored in a warehouse before loading and not in the outdoor storage. However, once the journey started it was subjected to high humidity range throughout the shipment.

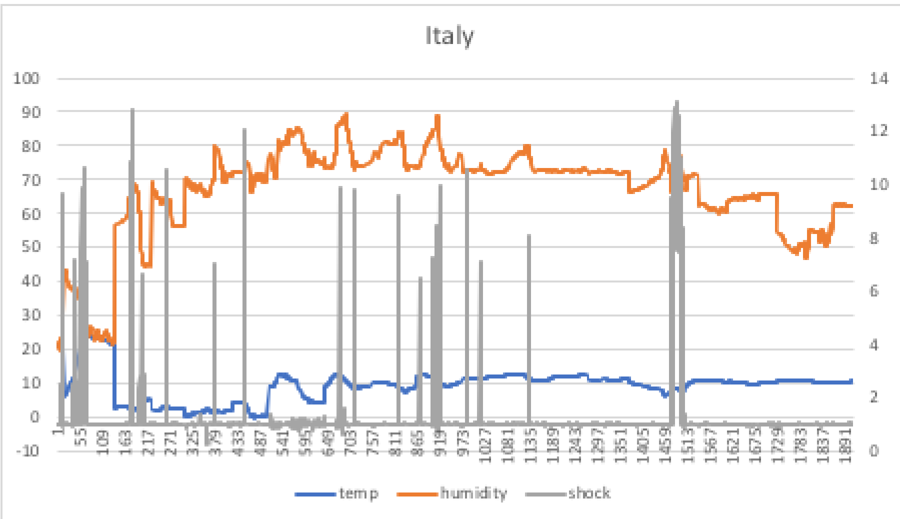

Figure 19. Sensor data from Lund to Italy

The packaging sent Czech Republic (figure 19) was exposed to a high shock of 10.88g within the Alfa Laval facility. Another high shock of 13g has been recorded during the transportation, it happened on the 15th of March which was the date of delivery to customer. Therefore, it can be assumed that the shock of 13g was recorded during the unloading of the package. For this package there were a series of shocks observed through the transport journey, which raises concerns about to quality of handling done by the external transport provider.

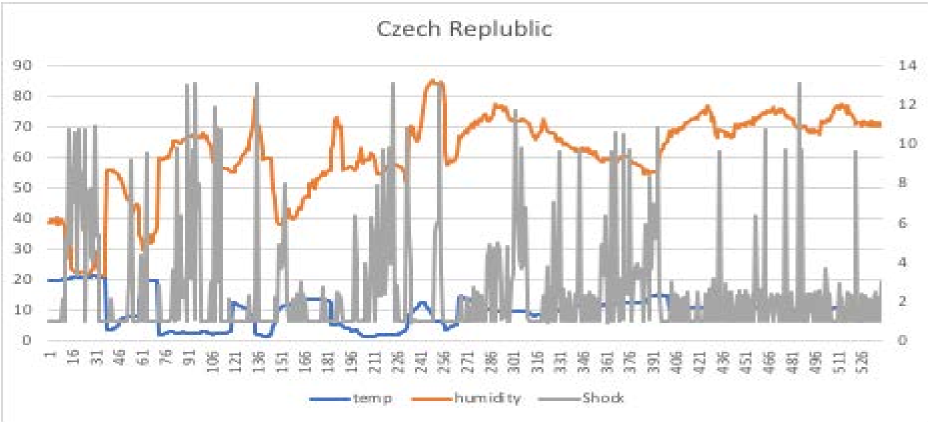

Figure 20. Sensor data from Lund to CR

For the packaging which was sent to Germany (figure 20), high shocks up to 12.24g were recorded within the facility in Lund. High shocks were also recorded during the transportation of the package to Germany reaching a magnitude up to 11.63g. In terms of humidity, once the product was moved out of the assembly line and kept in the outdoor storage it was exposed to high humidity, and it remained high throughout the transportation ranging between 70-85%.

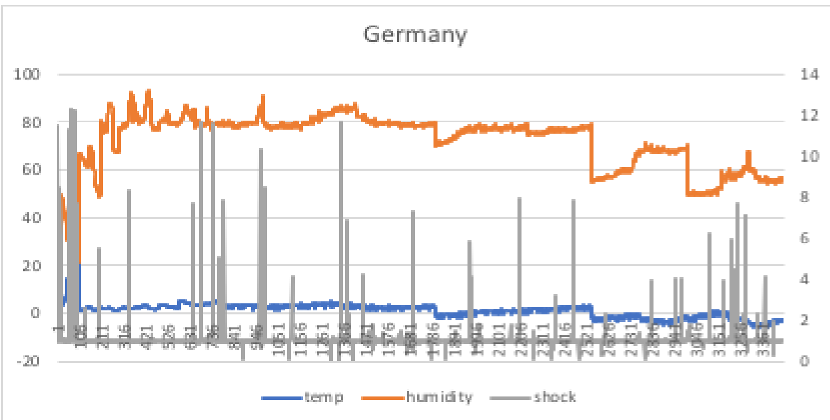

Figure 21. Sensor data from Lund to Germany

For the packaging which was sent to South Africa (figure 21) there were a series of shocks recorded on the day of loading that is on 2nd March. However, the highest shock was observed on the 4th of March reaching a magnitude of 12.84g, which according to the GPS data, would have happened on the port where the product was transferred from truck bed for ocean transportation. Otherwise, there was a negligible amount of shock recorded during both transportation modes which are road and ocean transportation. As expected, there was a high humidity range of above 80% during the ocean transportation and it is probably due to the ocean shipping conditions such as sea spray.

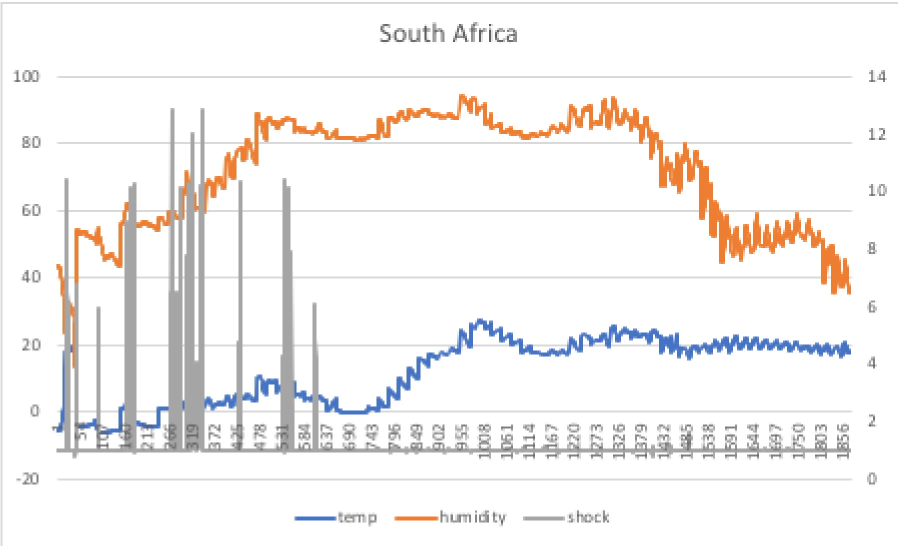

Figure 22. Sensor data from Lund to South Africa

For the package sent to Shanghai (figure 22) there was not much data recorded within Alfa Laval GPHE, as the package was kept within the facility for only one day. However, there was a shock of 7,36g observed during the loading of the cargo to the truck for transportation. In addition, there was a shock of 12,71g recorded during the transport journey, which according to the GPS tracker happened during handling in the port. There was an increase of relative humidity as the travelling progressed, again this is probably due to ocean shipping conditions such as sea spray.

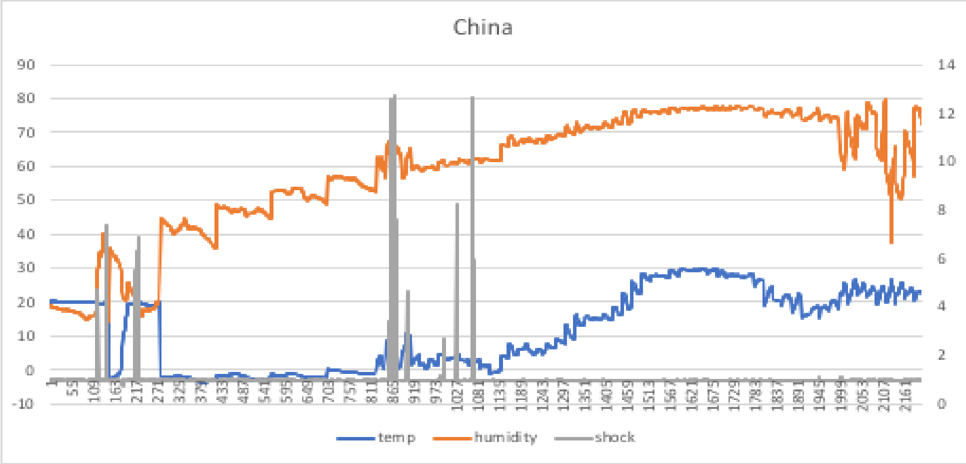

Figure 23. Sensor data from Lund to Shanghai

For the packaging sent to the UAE (figure 23), there was a shock of 12,76g recorded within the Alfa Laval facility and since the product was kept only one day within the facility it can be assumed that this shock was recorded during the loading process. There were frequent occurrences of shocks throughout the transportation journey. According to the GPS tracker, these shocks were recorded during the check or service points, as well as during both truck and ocean shipping. In terms of humidity, the cargo was exposed to high humidity throughout its flow in the supply chain. However, there were exceptions such as when the product was in Hamburg, where a low humidity value was observed. Once the package entered Saudi Arabia, where the transportation mode switched from ocean to road transportation, the humidity value was varying within a moderate average humidity range.

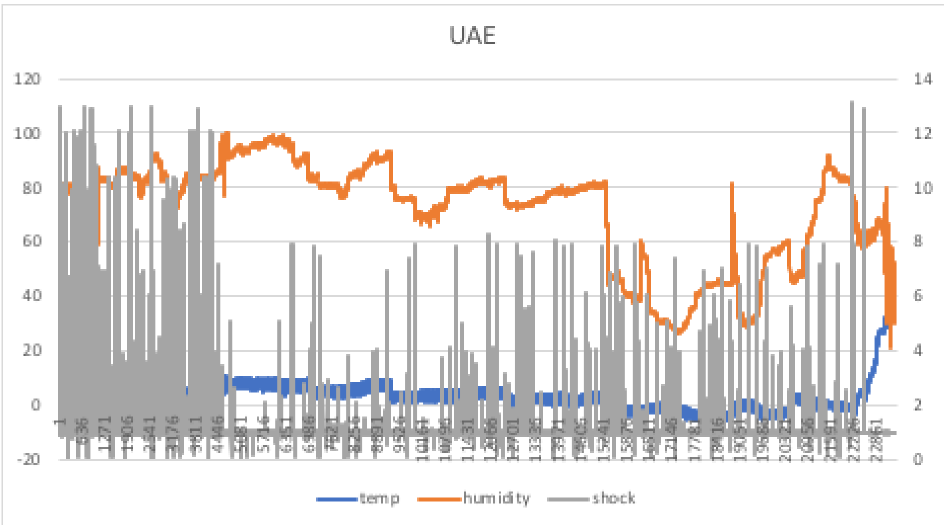

Figure 24. Sensor data from Lund to UAE

The data recorded in the various supply chains indicate that the cargo experiences frequent shocks and is exposed to relatively high levels of humidity. The frequency of and magnitude of shocks as well as the variation in humidity levels varies from one supply chain to another. There are however certain similarities and patterns, these will be further discussed in the following section.

5 RESULTS ANALYSIS AND DISCUSSION

In this chapter the data collected through the various methods will be analysed, the main results will be presented and explained.

5.1 The supply chains conditions through sensor data analysis

The purpose of this section, is to use sensor data to identify the conditions that the industrial packages are subject to, independently, inside the Alfa Laval facility in Lund and outside of it during transport. Then, a comparison between the conditions in the two phases will be made in order to identify any existing similarities or differences. Throughout this section, the effects of the identified conditions on the packaging in terms of risk of damage and requirements will be discussed.

In this section, the researchers have analysed the data collected by the sensors sent to different destination in order to identify potential similarities or patterns in the supply chain conditions. In order to get the most knowledge from the collected data, the researchers decided to differentiate the collected data into two phases. The first phase groups the data recorded within the Alfa Laval facility in Lund. The second phase, relates to data collected during the transportation process that is from the day of loading the product to the truck and until the truck reaches its destination. The analysis of the two phases will provide a better understanding of the conditions that the industrial package is subject to throughout the supply chain, in terms of handling, temperature and relative humidity.

5.1.1 Conditions inside Alfa Laval GPHE

In this section, the researchers separated the sensor data collected during the dates in which the products and their packaging were inside Alfa Laval GPHE. The operations inside the Alfa Laval GPHE facility are packing the product in the packaging assembly line, moving the packed product to the storage area and finally picking it from the storage area to load it into the truck. The conditions monitored are temperature, shocks and vibration. The data collected are summarized below in the tables 8 & 9 and figures 24, 25 & 26. This analysis will help in understanding the overall handling and storage conditions happening inside the Alfa Laval facility. Storage conditions will be identified by interpreting the humidity recordings, and information about how the packaging has been handled under different processes can be obtained by analysing the shock data.

Table 8. Data Collected from Sensor while the package is inside Alfa Laval

Destination	**Temperature (^{0}C)**		**RH (%)**		**Shock (g)**	
	Min	Max	Min	Max	Min	Max
Czech Republic	3.2	21	21	55.7	0.99	10.59
Spain	2	21.9	19.8	70.6	0.94	13.14
Italy	2	24.9	19.6	70.4	.89	12.8
Nacka 1	-9.2	21.7	22.8	99.1	1	9.45
Nacka 2	-5	22	11.9	90.9	0.89	10.59
Germany	0.8	23.8	19.9	92.7	0.8	12.24
Spain 2	2	22.2	19.8	70.6	0.42	13.14
UAE	17.8	20.7	23	29.5	0.92	12.96
China	19.3	24.5	14.4	40	0.92	7.36
South Africa	-6.1	23	13.8	63.4	0.77	10,37

In terms of shock, the researchers noted that there is always high shock values recorded within the Alfa Laval facility (figure 24). The recorded shock data shows a similar pattern for all packages while inside the facility in Lund. These patterns are that shocks of high magnitude and short period occurred in two to three phases. In this project, there was only 3 main operations that took place within the Alfa Laval facility after the sensors were installed into the packages. Therefore, these shocks can either be recorded during the packing operation in the assembly line, or during picking & moving to storage area, or it can be recorded during the picking from the storage area & loading of cargo to the truck.

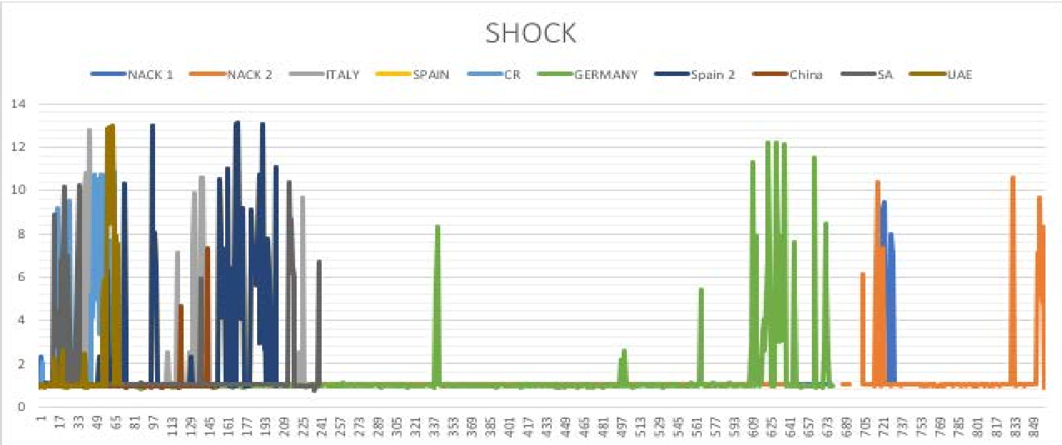

Figure 25. Shock recorded within Alfa Laval

Regarding humidity, the sensor data indicates that the package and the product have been subjected to high relative humidity within the Alfa Laval facility this can be explained by the fact that packages are stored outdoors before loading. The open storage facility means that there is a constant interaction between the package and the external environment which raises the concern of exposure to rain, wind and snow. It should be noted that the period in which these measurements were made, was from March to April 2018. This was an exceptional winter period where the temperature was lower than usual, in addition to strong wind and heavy snowfall. Therefore, these readings do not represent the status of the climatic conditions over the entire year. However, Sweden remains a country in which the climate is relatively cold for a number of months over the year. As a matter of fact, weather reports state that the average relative humidity reported in Sweden is around 79% for the entire year. Hence, it can be concluded that having a closed storage facility is an option for Alfa Laval GPHE to avoid subjecting the packages to risks related to high relative humidity and its factor such as rain, snow and wet surface. However, this will require significant investments for the construction of new storage facility.

Finally, some packages recorded a lower average humidity at the Alfa Laval facility, this was due to the fact that these packages were stored for a short period of time within the facility before being loaded in the trucks.

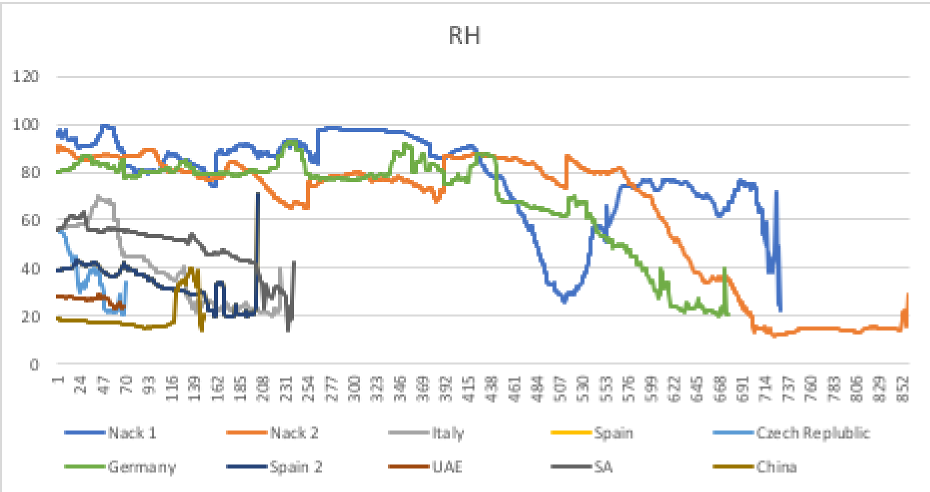

Figure 26. Relative Humidity recorded within Alfa Laval

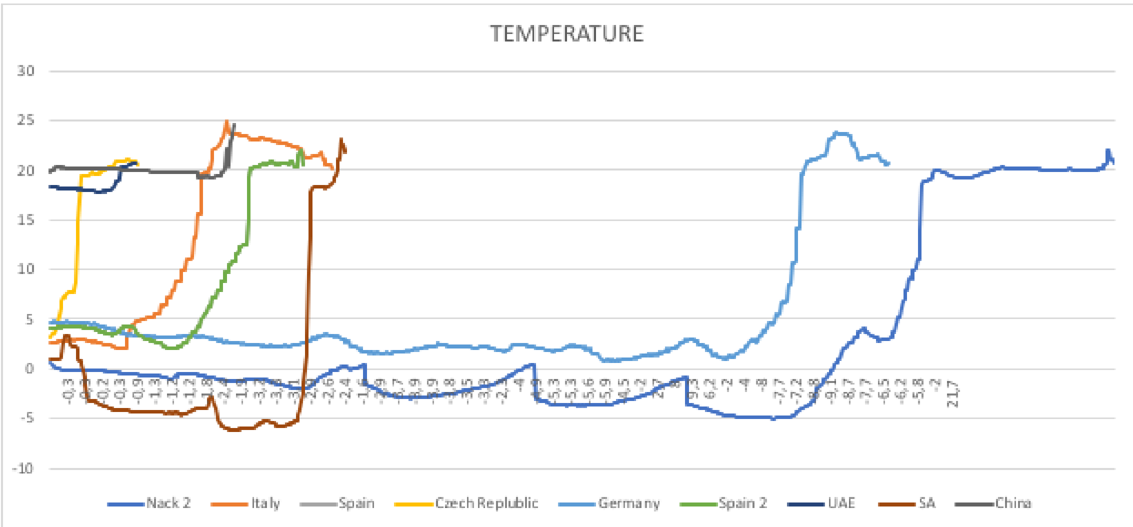

Figure 27. Temperature recorded within Alfa Laval

Table 9 Average RH and temperature within Alfa Laval

Destination	Average Relative Humidity	Average Temperature
Nacka 1	78.62	-2.63
Nacka 2	63.47	2.49
Italy	39.48	13.09
Spain	33.21	8.26
Czech Republic	35.69	15.82
Germany	35.69	15.82
Spain2	36.7	10.3
UAE	26.90	18.54
SA	48.76	-0.77
China	19.97	20.02

5.1.2 Conditions during transport

This section deals with data collected once the packed product is loaded into the truck bed and starts moving toward its destination through various transport routes. Temperature, shock and relative humidity were monitored in order to identify the overall supply chains conditions during the external transport phase, and their impact on the product and its packaging. The data collected is summarized in the Table 10 and figures 27, 28 & 29 below.

Table 10 Data Collected from Sensor while the package travelling towards destination

Destination	**Temperature (^{0}C)**		**RH (%)**		**Shock (g)**	
	Min	Max	Min	Max	Min	Max
Czech Republic	1	15.4	37.7	85	0.87	13.07
Spain	2.8	21.3	39.3	77	0	13.25
Italy	2.8	12.8	56.3	89.2	0	13.14
Nacka 1	0	10.8	95.5	100	0.93	1.08
Nacka 2	0.2	10.1	55.2	93.3	0.93	1.09
Germany	1.1	4.8	76.4	90.8	0.02	11.63
Spain 2	1.8	13.1	37.5	93	0.93	13.14
UAE	-6.7	37.6	21	100	0	18.4
China	-3.6	29.7	15.6	77.9	0.76	12.71
South Africa	-4.4	54.2	1	93.8	0.78	12.84

The collected data indicates that during the external transport outside Alfa Laval GPHE, there are 3 phases during which there is a possibility of shocks to be recorded. The first phase is during the flow process, which is when the product is on the transport vehicle and on the move towards the customer place. The second phase is at the dock, where the product is transferred from one transportation mode to another (e.g. from truck to ship).

The third phase in which shocks can be recorded, is during the unloading process at the customer's facility. All cargo shipped within the EU and to china recorded a relatively low amount of shocks during the flow phase, in comparison to the products sent to South Africa and UAE. This may be due to variation in the quality of infrastructure, transport service providers or due to the difference in the shipment distance and length.

Regarding ocean freights, the cargo sent to both South Africa and Shanghai (China) have not experienced shocks during its travel time in ocean while the cargo was on the ship. Instead, the shocks were experienced during road transport (Truck) and during change of transport mode. However, the cargo shipped to the UAE was exposed to a series of shocks both during the ocean transportation (cargo on the ship), during transport mode change and once it entered the UAE for truck transportation.

Overall, a large amount of high magnitude shocks have been observed for the various supply chains. These shocks were mainly recorded during three operations, during truck transportation, during handling in port and during unloading at the customer facility. These supply chain conditions put a requirement for strong packages with a protective ability that withstands frequent and high magnitude shocks. It is important to note that as no damages were reported during this project and due to the unavailability of packaging specifications relating to the current packaging's strength. It cannot be concluded whether the current packaging enables optimal protection against the identified supply chain conditions or not.

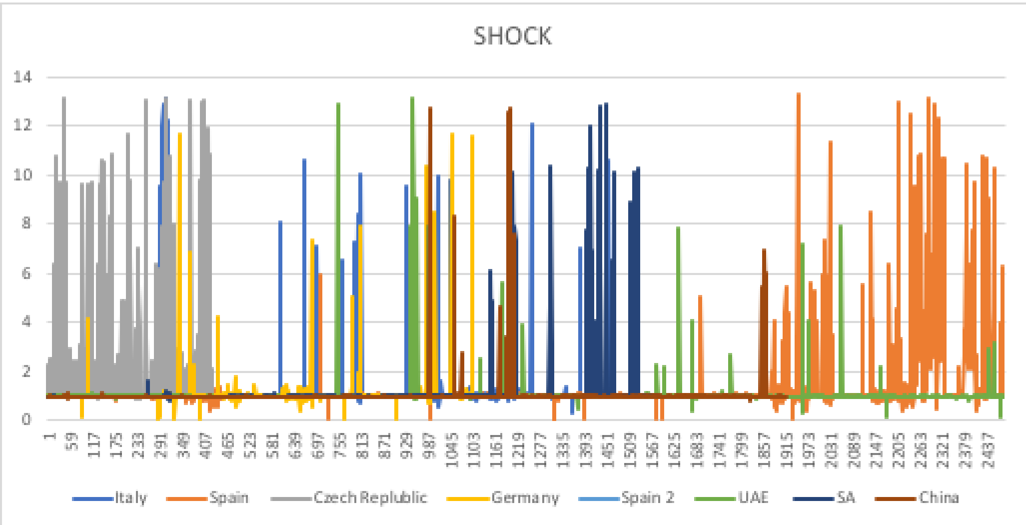

Figure 28. Shock recorded during transportation

By analysing the overall Relative humidity values recorded, it can be said that exposure to high humidity ranges is expected during the period of transportation especially within Europe. In addition, the average temperatures recorded are relatively low within Europe. The relative humidity recorded for shipments to non-European countries was also high, especially during the ocean shipment. Overall, the recorded range of relative humidity is very high during transport, which raises the concern that the wood moisture content could raise and lead to the decay of wood or structural damages due to the absorption of moisture. Thus, Alfa Laval GPHE should consider designing packages that provide a superior protection against humidity especially for transport within the EU during winter and for ocean shipments.

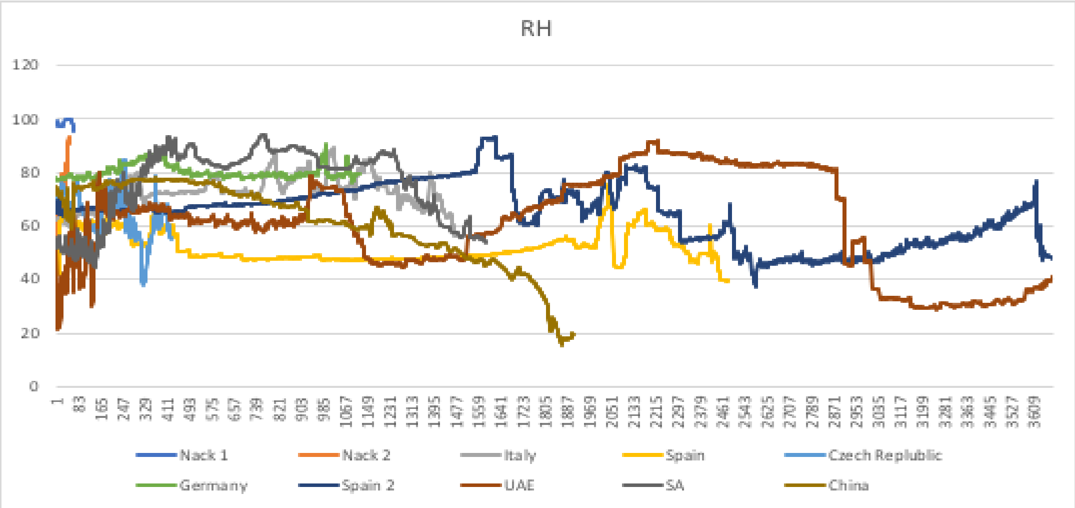

Figure 29. Relative humidity recorded during transportation

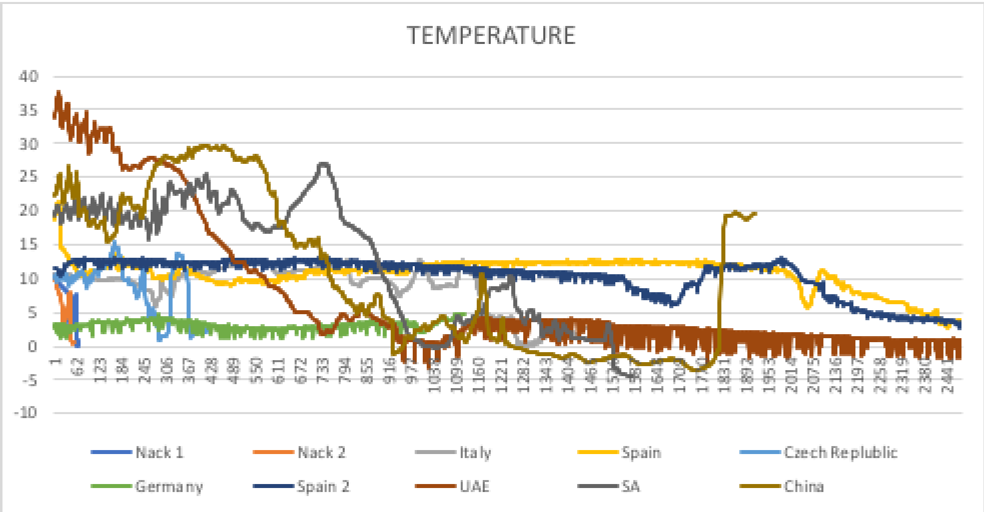

Figure 30. Temperature recorded during transportation

Table 11 Average RH and temperature during transportation

Destination	Average Relative Humidity	Average Temperature
Nacka 1	98,65	6,54
Nacka 2	74,34	5,37
Italy	72,35	8,64
Spain	52,06	10,78
Czech Republic	64,21	8,54
Germany	64,21	8,54
Spain 2	64,6	10
UAE	71,51	4,06
SA	76,10	12,72
China	60,92	10,33

5.1.3 Overall Summary of sensor data results and supply chain conditions

The findings from the sensor data are summarized in this section to give an overall description of the conditions the cargo is exposed to throughout the supply chain. The first unexpected finding from the Sensor data is that the shock levels recorded when the product was within the Alfa Laval GPHE facility were higher than initially assumed from the conducted observations and interviews. Even though the highest number of occurrence of shock was recorded during the transportation, there were incidents of high shock recorded within the Alfa Laval GPHE which in most cases were the maximum shocks recorded for the packages. As a matter of fact, shocks of high magnitudes between 9.5g and 13g were recorded inside Alfa Laval for almost all packages. This led to the reliability of such recorded values to be put into question, as no damage claims were reported during this project. This was discussed with the technical support of the sensor provider, who stated that high g-force can definitely happen in quick short burst. He gave the example of a device dropped on to a hard surface, it stops almost immediately which creates a short but very high g-force. Essentially, the shorter the shock event is, the higher the force.

Regarding humidity, the recorded findings could not be classified according to geographical regions, as they were relatively similar for the different supply chains. As a matter of fact, the current packaging system has been exposed to high levels of humidity both within Alfa Laval GPHE facility and during the transportation (Figure 30). These common findings of relatively high humidity in the various supply chains, can be explained by the cold climatic conditions within Europe during the project timeline and by the ocean shipping conditions favouring high moisture levels (e.g. cargo sweat and sea spray). Though the cargo was not constantly exposed to high humidity during the entire journey, there were packages that were exposed to high humidity for successive days. In addition, variations in temperature and humidity happened once the cargo moved out from the Alfa Laval production site in Sweden. The significance or range of the experienced variances differs greatly depending on the transport route used. For instance, some cargo shipments experienced significant variations that reached a variation of temperature up to 43 degrees and relative humidity up to 71%. Overall, the humidity data findings raise concerns about the growth of moulds, the wood changing in size and losing its consistency which could potentially lead to the collapse of the package.

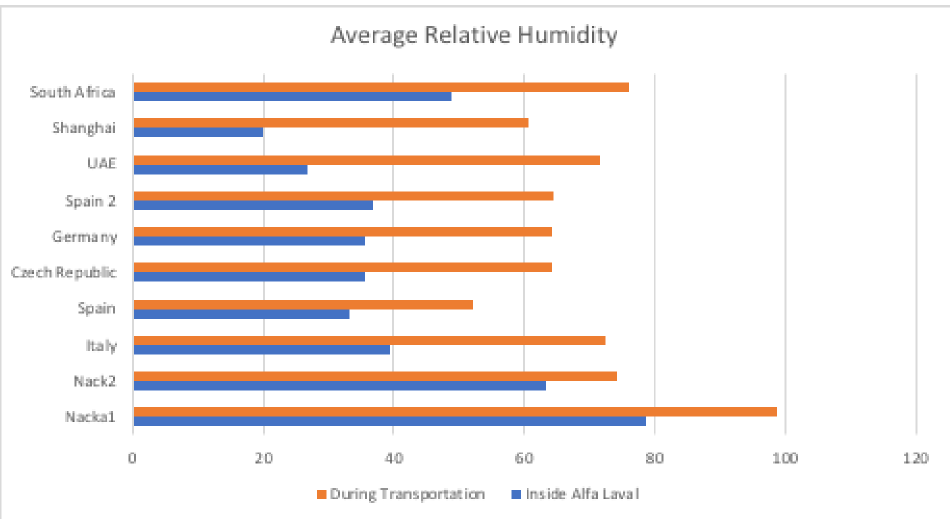

Figure 31. Comparison of Average RH within facility and during Transportation

In Table 12, the researchers present the overall supply chain conditions in terms of shock and humidity, the inherent risks and the processes in which they usually occur. In addition, the requirement columns lists the requirements these humidity and shock conditions put on the package and the various transport related processes. Noteworthy that in this chapter section, some risks were identified through the analysis of the recorded data. However the overall risks, their factors and typical situations in which they occur will be discussed in details in the following section of this chapter.

Table 12. Overall Summary

Conditions	**Process**	**Risks**	**Requirements of Packaging**	**Requirements of Process**
High Shock (6-13.5g)	Mainly during loading and unloading in Alfa Laval facility, at ports and at the customer facility	Stress cracks Packaging deformation or failure	Ability to withstand high and frequent shocks	More cautious handling Better service level agreement (SLA) and communication with external transporters
High Humidity (70-100%)	Across the whole supply chain	Loss of compressive and bending strength Growth of moulds.	Ability to withstand exposure to high humidity	Better storage where humidity can be controlled

5.2 **Potential risks and their driving factors**

The purpose of the second section in this chapter, is to use literature and data collected by all methods (internal documents review, observations, interviews and sensors) to identify all the potential risks for damage, their influencing factors and finally to establish the link between them and provide examples of the typical situations in which these damages occur.

After reviewing literature about risks in transport, logistics in developing countries and analysing the data gathered from damage register, interviews, observations and data loggers. A risk-factor map was developed (Figure 35), it lists both the identified potential risks and their influencing factors and classifies them into different categories. Noteworthy that in this thesis work, risks are considered to be the various ways by which both the product and the industrial package may deteriorate or be damaged. In addition, risk factors refer to the properties of products, packages, processes, climate, infrastructure and forwarders involved, that cause the risk to occur and influence both the frequency of its occurrence and the degree of damage it causes. It is important to note that a certain risk can be influenced by multiple risk factors and that a certain risk factor may influence multiple risks. In the following sections, the potential risks and their influencing factors will be discussed and their classification will be motivated. Moreover, the link between the risks, the typical situations in which they occur and the influencing factors will be described and summarized in table 13.

5.2.1 The potential risks

In the developed risk-factor map, the risks were classified according to their nature as suggested by Corner and Paine (2002). The first risk category is mechanical risks, which refers to damages caused by static forces such as compression or by dynamic forces such as vibrations and impacts. The second risk category combines chemical and biological risks, which refers on one hand to damages caused by chemical reactions such as corrosion and on the other hand to damages caused by biological activities such as wood decay. The final risk category was labelled as miscellaneous risks referring to the potential risks that were not the focus of this project, due to their low frequency of occurrence.

The presence of the risks will not necessarily cause significant damage, as a matter of fact, considerable damages will only occur after the exposure to the risk for a certain period, frequency or exceeding a threshold of a certain parameter. In addition to the information previously cited in the literature review in table (5) which listed the potential risks and the data needed to determine whether a risk will lead to a significant damage. Table (13) below compiles the product and packaging properties affecting the degree of damage.

Table 13. Potential Risks and the situational, product and package properties affecting the degree of damage (Natarajan et al. 2015; Jorgenson 2015; Corner and Paine 2002; Goodwin and Young 2010, Mendoza and Corvo 2000, Vursavus and Ozguven 2004, Russell and Kipp 2006, Kubiak et al. 2009).

Risks leading to damage	Properties affecting the degree of damage	Product & packaging properties affecting the degree of damage
Shocks (Drops and impacts)	Height of fall, position and direction of impact, Frequency of drops, Impact velocity, Characteristics of the impacted surface or nature of the impacting object	Fragility factor Package strength
Crushing & compression **Bending & deformations**	Origin of the force (stacking, strapping, nets) Stack height and weight , Material of straps and slings	Safe loading Compressive strength Modulus of elasticity
Vibration	Amplitude, acceleration, frequency, continuous or periodical presence of stacking loads or side loads,	Critical frequency ranges Package strength
Abrasion & surface markings **Puncturing, tearing & proliferation**	Nature of abrasive element (e.g. sand particles) or abrasive action (e.g. rubbing, erosion) Contact force or pressure Difference of surface hardness in contact areas	Type of surface finish & coating Package strength
Corrosion & material degradation	Atmospheric conditioning (e.g. Moisture, relative humidity and temperature variations) Duration of exposure	Product materials Type of surface finish Critical relative humidity ranges Critical temperature limits
Biodeterioration (e.g. wood decay)	Atmospheric conditioning (e.g. Moisture, relative humidity and temperature variations) Duration of exposure	Type of packaging material Use of treatments

5.2.2 Product and packaging factors:

This risk factor category contains the various aspects related to the product and its packaging system, which influence risks of product or package damage.

First, the main product related risk factors that can lead to damages relate to the materials from which the product's components are made. The data regarding customer complaints revealed cases in which corrosion has been reported. This issue can be caused by the non-use of proper surface finish treatments and protective coatings. As sensor data indicated that the product and its package can be subject to a high relative humidity up to 92,7%**.** The risk of corrosion may also be linked to the use of packaging systems that do not provide an effective protection against moisture.

Second, the packaging factors relate to the packaging system selection, the packaging process and the packaging design. One of the packaging related risk factors is the usage of packages that are not protective enough to deliver products. This situation may itself be linked to the current sales system that does not promote the selection of an appropriate package. Currently, the salesperson tasks include suggesting the product configurations that suit the clients' needs, as well as discussing which packaging system to be used during transport. As previously discussed, it is the customer that makes the final decision about the product configuration to be purchased and the packaging system to be used. As a matter of fact, a great number of customers are primarily focusing on minimizing costs and choose to select the cheapest packaging system instead of the most suitable for the freight journey. In addition, it is not clear whether the customer is made aware of all the possible risks and this can be explained by the fact that the sales personnel are focusing on achieving their sales targets and or not being familiar with the potential risks. The sales process in its current state should be considered as a risk factor that can lead to the use of underspecified packaging which does not provide the necessary protection to the product and consequently causing it to be damaged during transport.

Another packaging related risk factor linked to certain product and package damages, is the packaging procedure at Alfa Laval GPHE. During the observations of the packaging process and interviews with the packaging operators, it was noticed that some aspects of the packaging procedure are not uniform and conducted differently by different teams. The main difference and the one which could have a great influence on product stability is related to the skidbase boards added to position the GPHE units on the skidbase. These boards are strapped and screwed to the skidbase by one packaging team (Figure 31), while the other team only places them over the base with no further fixations (Figure 32). This is a factor that may potentially be the main cause to some GPHE units dislocating from the skidbase and tipping over during transport.

Figure 32. Skid with fixation

Figure 33. Skid without fixation

The outdoor storage of packages at Alfa Laval GPHE has also been connected to certain risks. According to the current process, once the GPHE units are tested and packed, they are either stored in indoor warehouses or outdoor storage zones. Based on the collected data from the sensors, interviews and observations, it was perceived that the outdoor storage exposes the industrial packages to climatic hazards that can lead to the package losing its strength and consequently its protective ability. As a matter of fact sensors indicated that while packages were stored outdoors at Alfa Laval GPHE they having been subject to a humidity of 99.1% which can cause the deterioration of the wooden packaging. As a matter of fact, when relative humidity is above 90%, the risks of mould growing on wood increases, which leads to structural damages of the wood (RLC engineering 2010). The exposure to high humidity leads to changes in the wood size and consistency (Wengert 2013). Consequently, as the wood loses its consistency, the straps that hold and fix the product to the skidbase are loosening which can cause the product to move inside the ocean packaging or tip over.

Finally, many risks have been linked to the packaging design methodology. As a matter of fact, the data analysis pointed out that the packaging design process has been person-centred in a way that there was no structured packaging design approach. In fact, the packaging design process for new products has been based on past experiences and what has previously worked well with products of similar form, dimensions and weight. According to conducted interview, the lack of an adequate packaging design methodology has caused damages such as pallets being too narrow for the product and causing it to tip over. Another example of how design based only on past experience led to damages, is related to some newly designed skidbases being too weak to withstand the product's weight thus leading to cracks in the skidbase and damage of product components. It is important to test the packaging design performance, especially in high values products for which damage expenses are highly significant (Goodwin and Young 2010).

5.2.3 Human factors

This risk factor category regroups the human factors that can cause product and package damages. These risk factors are mainly related to human errors and the fact that operators may lack proper qualifications and training. The lack of training and expertise can lead to a rough and careless handling that damages products and packages. It is noteworthy that the occurrence of risks related to the previously cited factors intensifies in developing countries where the use of untrained temporary workers is a common practice due to the lack of equipment and cheap labour costs (Prater et al. 2009). The lack of training and desire to increase space efficiency can also lead to an inadequate handling such as having stacking heights and top loads exceeding the recommended limits. Moreover, the rough working conditions, long shift hours and low wages in developing countries increase the risks of rough and careless handling (Sohrabpour et al. 2012). Noteworthy that in contrary to initial assumptions that the researchers had, rough handling is not a risk encountered only in developing country. As a matter of fact, data retrieved from the data loggers have indicated that intense shocks have occurred at the Alfa Laval GPHE facility reaching a magnitude of 13,4g. The rough and inadequate handling which exposes the packages to such recorded shocks puts multiple requirements on the packages such as having a great compressive strength and top-load stacking strength (Sohrabpour et al. 2012).

5.2.4 Climatic factors

This risk factor category groups all aspects related to climate that influence the occurrence and degree of product and packaging damages. There are multiple climatic factors that can lead to the damage or deterioration of a product and its package. For instance, the climatic conditions that are encountered in the Lund area such as strong wind, causes the industrial package handling to become highly complex. During the conducted interviews, the internal logistics operators stated that the climatic conditions encountered during winter causes the road surface to become slippery and can reduce the forklift driver's vision which occasionally causes packages to be dropped. Other climatic factors that are damaging to both the product and the industrial package are related to humidity, sea spray and rain water which can be encountered during transport, handling and storage. As previously mentioned, sensor data indicated that packages can be subject to humidity up to 99%. The previously cited factors can, for instance, cause corrosion and other types of surface degradation of the product and its components. As a matter of fact, the presence of moisture and other corrosive contaminants in the air causes the so called atmospheric corrosion (Mendoza and Corvo 2000). It is noteworthy that the presence of sea spray worsens the degree of surface quality deterioration. Such climatic factors can also enable the growth of parasites and wood decay causing the package to lose its strength and consequently its protective ability (Wengert 2013; RLC engineering 2010).

5.2.5 Communication factors

This risk factor category comprises the aspects associated to communication between the various forwarders that can influence the occurrence and degree of product and packaging damages. The information gathered from observations and interviews revealed that there are obstacles to a good communication between the various forwarders involved, as well as a lack of knowledge transfer amongst them. Both poor communication and the lack of knowledge transfer can be the cause of product and package damages. One example is the fact that many truck drivers that come to pick up cargo from Alfa Laval GPHE do not speak Swedish or English. The language barrier makes the communication rely mainly on non-verbal cues such as hand gestures. It is important to note that the GPHE units are complex to handle, most of the forklift drivers at Alfa Laval GPHE have worked there for many years and acquired a great knowledge on how to safely and effectively handle these industrial packages. However, the language barrier limits the ability of Alfa Laval's personnel to fully assist the truck drivers in safely and effectively handling the loaded packages.

In addition, incidents have occurred due to packages not being secured enough to the cargo container bed. This has caused packages to be mobile inside the cargo container and consequently tipping over (Figure 33) or impacting other goods. This can be explained by the fact that the external forwarders may not be familiar with the transported products and do not have the knowledge to effectively handle these packages. This situation raise the question about another aspect of communication that can be improved, which is the transfer of knowledge or best practices from Alfa Laval GPHE to the other forwarders involved. Currently the main form of best practice transfer is the cargo securing instructions (Figure 34) document that is pasted on the industrial package. The goal of the cargo securing document is to provide information to the external forwarders on how to safely handle the GPHE units. However, this document is currently not available for all GPHE units and again the language barrier may limit its usefulness.

Figure 34. Product tipped over in the cargo container due ineffective securing

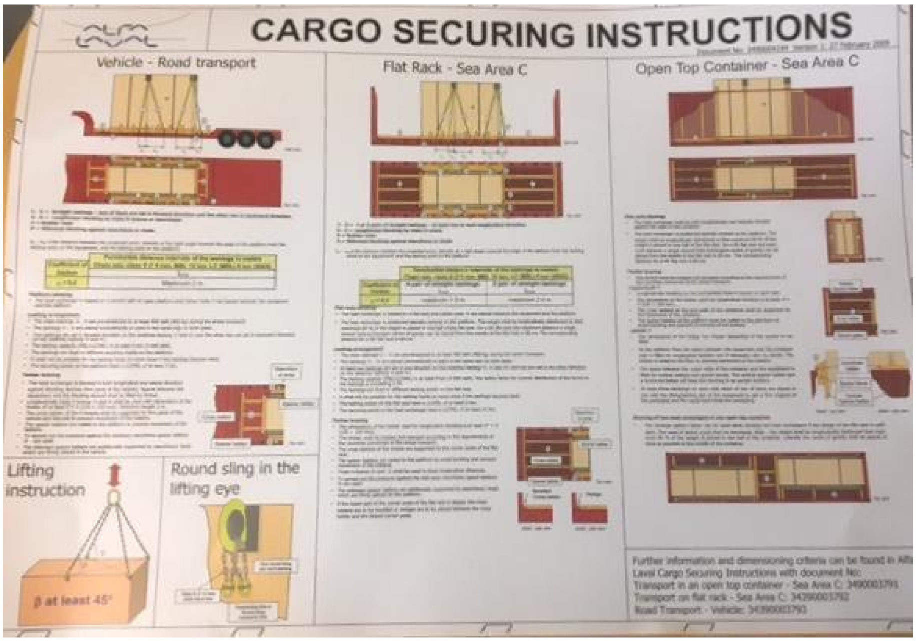

Figure 35. Cargo securing instructions document'

5.2.6 Transport, handling and storage factors

This risk factor category contains all the aspects related to transport, handling and storage operations that can influence the occurrence and degree of product and packaging damages. Every year Alfa Laval receives around 30 to 50 claims about product and packaging damages that occurred during the shipment journey. The risks of product and package damage are highly influenced by the state of the roads and the quality of infrastructures. As a matter of fact, poor road tracks with holes and bumps lead to an increase in the number of shocks that can result in cracks, deformations and surface scratches. The availability of handling facilities (e.g. docking stations) and good equipment (e.g. cranes and forklifts) is another important factor that influences the occurrence and degree of damages.
For instance, the use of defected forklifts or cranes can easily cause the bending or puncturing of the package. Another example is the absence of loading platforms which increases the risk of drops. The availability of storage facilities that are in a good condition will prevent the exposure of products and packages to rainfall, humidity and sea spray which are the main causes for corrosion of metals, wood decay and loss of consistency (Mendoza and Corvo 2000; Wengert 2013). The state of the cargo container is also important as defected ones (e.g. truck beds with holes) can cause damage such as the deformation of the skidbase due to uneven support. In addition, old containers without proper ventilation or allowing the formation of cargo sweat can lead to surface degradation due corrosion or contact with rusty container walls. The vehicle configuration is also an influencing risk factor, for instance, the transport vehicle suspension system will play a role in lowering the impact of poor road tracks (Hones et al. 1991; Vursavus and Ozguven 2004). However, in developing countries it is a common practice to use vehicles with outdated technologies or equipped with steel leaf suspension systems which exposes cargo to increased shocks and vibrations (Sohrabpour et al. 2012). Finally, it is important to note that the duration of the transport and the extensiveness of loading and unloading will influence the occurrence of damages of products and packages. As the transport duration is longer and the number of transfer points grows the package will be more exposed to risks such as drops, deformations and corrosion. This was confirmed by Stock and Lambert (2001) who argues that, "The greater distances and number of times products are handled increase the possibility of damage, delays, and pilferage".

Table 14. Potential risks, their typical situations of occurrence and the risk factors affecting the degree of damage

Potential risk	Typical situations causing damage	Factors influencing damage
Shocks (Drops and impacts)	-Package dropped during Loading/unloading (from cranes or forklifts) -Package falling from nets or conveyors, storage shelves or platforms -Package impacted by another package (start & stop of vehicle, swinging crane) -Package impacted by a moving object or vehicle -Package tipping over in truck bed or cargo container -Package manually rolled or thrown	Product & packaging Transport & handling Climatic Communication Human
Crushing and compression **Bending and deformations**	-Compression due to stacking loads in storage or during transport (crushing with excessive stacking height/load) -Compression by misuse of handling tools (straps, cranes, nets) -Bending and deformation from unbalanced base support from defected truck beds, floors and erroneous lifting	Product & packaging Transport & handling Communication Human
Vibration	-Bouncing of package load, loosening of fasteners and movement of components due to vibrations from the road conditions (e.g. bumps, cracks) and from the transport vehicle (Engines, suspension systems)	Product & packaging Transport & handling
Abrasion & surface markings **Puncturing, tearing & proliferation**	-Abrasion due to wrongful handling (e.g. drops and Impacts with other packages) or due to misuse of equipment (e.g. damages by forklift) -Contamination by contact with handling equipment (e.g. rusty strapping, metal wired nets) -Impact by projections (e.g. metal residues, sand particles)	Product & packaging Transport & handling Communication Human
Corrosion & material degradation	-Exposure to rainfall, sea spray, water puddles, cargo sweat and humidity from the atmosphere -Exposure to chemical pollution (in atmosphere and spray) -Exposure to extreme variations in moisture and temperature	Product & packaging Transport & handling Climatic Communication Human
Biodeterioration	-Exposure to climatic conditions (e.g. temperature and moisture) favouring growth of microorganisms -Exposure to infested environments (e.g. fungi and bacteria)	Product & packaging Transport & handling Climatic Communication Human

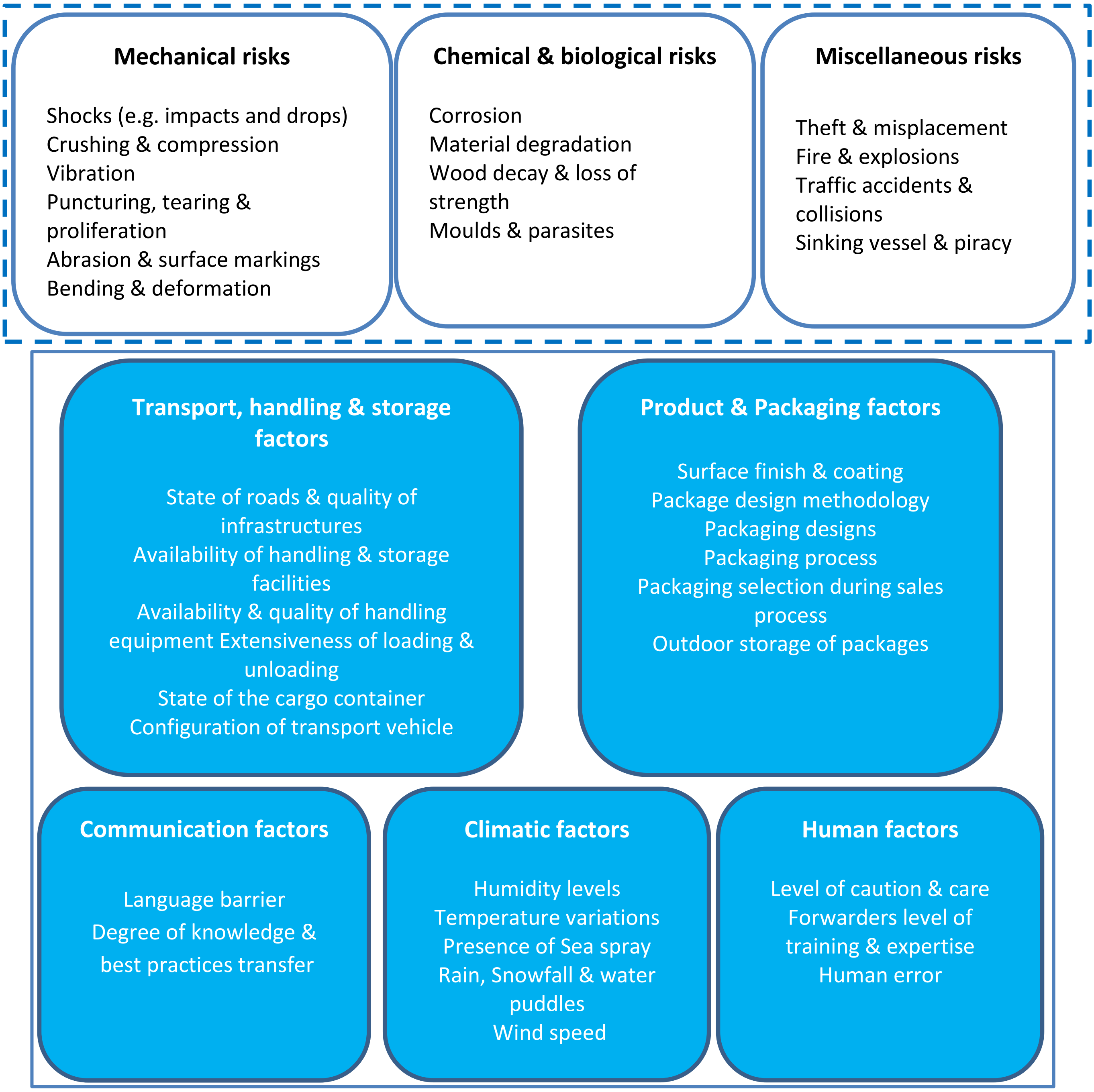

Figure 36. Risk-factor map

6 CONCLUSIONS

In this chapter, the main findings will be summarized as answers for the research questions, and the theoretical and practical implications of the study will be presented.

This thesis work has provided essential information regarding the conditions that both the product and the industrial package are subject to throughout the supply chain. In addition, the thesis results have clarified many aspects related to global cargo transport and proved some initial assumptions to be wrong.

First, the transported cargo was found to be exposed to relatively similar conditions across the various supply chains studied in this project. As a matter of fact, the gathered sensor data indicate that all packages were exposed to high humidity and multiple shocks that varied in intensity and frequency. Second, in contrary to initial assumptions, the shipped cargo was not found to be exposed to the most damaging conditions during transport mainly. As a matter of fact, the thesis results indicated that shocks of high magnitude occurred within the Alfa Laval GPHE facility as well. These shocks were low in frequency and happened in short time, but they were very high in g-force magnitude. Third, another finding that contradicted initial assumptions was the fact that the conditions the cargo is exposed to in developing countries were not worse than the conditions in developed countries. The sensor data indicates that the shocks rate increases in long distance shipments, which was due to the extra handling activities (e.g. change of transportation mode in ports). Nevertheless, the intensity/magnitude of shocks haven't raised considerably in the studied developing countries. However, it is important to note that the results found for supply chain conditions in the studied developing countries, cannot be generalized for all the other developing countries due to variations in quality of infrastructure and climatic conditions between countries.

This thesis project enabled the identification of the potential risks that can lead to the damage or quality deterioration of both the product and its industrial package. The identified risks have been classified according to their nature as the following, mechanical, chemical & biological, and miscellaneous. The choice of such classification was motivated by one of the main thesis findings which was that the potential risks that can cause damage are relatively similar across the different supply chains studied in this project. The implication of this on a practical level was that the initially desired risk classifications according to regional characteristics such as developed countries versus developing countries was not the optimal risk classification method. This also entails that establishing a system defining packaging specifications (e.g. shock and moisture protection) according to regional characteristics would not be the most optimal solution. Instead, the package needs to have superior protective abilities against high humidity and frequent high magnitude shocks.

The risk factors influencing the occurrence and degree of damage have also been identified. The risk factors were classified according to what they relate to, as follows, the product & its package, the human factor, the communication between the forwarders, the climatic conditions and finally the factors related to activities of transport, handling & storage. The risk factors can also be classified into internal and external factors, the internal factors are the ones that Alfa Laval GPHE can directly influence such as the packaging design, the packing process and the transfer of knowledge with other forwarders. On the other hand, the external risk factors are factors which cannot be directly controlled such as climate, infrastructure quality and human errors. However, a protection can be provided against them through adequate packaging. The link between the potential risks, the risks factors and the typical situations in which the damages occur have been identified and summarized in table 14. This thesis results provided an overall insight of the cargo transport conditions, its inherent risks and their driving factors. This will enable organizations to have a better foundation to make decision about their product and packaging systems designs in order to achieve a higher cargo protection that limits the occurrence of damages and quality deterioration.

Finally, the identification of the shipment conditions, the potential risks and their influencing factors, has revealed certain aspects that present opportunities for improvement to close the gap between the various supply chain requirements and the current packaging system. Overall, the package needs to have superior protection against high humidity levels and frequent high magnitude shocks throughout the supply chain. Solutions to improve the cargo protection during transport have been found and will be discussed in the next chapter along with suggestions for future research.

7 RECOMMENDATIONS AND FUTURE RESEARCH

In this chapter, recommendations for potential improvements will be suggested and motivated. The following recommendations listed below, have been made based on the conducted analysis and the results found in this project. Finally, suggestions for future research will be discussed.

7.1 Develop and adopt a packaging design methodology

The packaging design process has up until recently been highly person-centred, in a way that only one person was in charge of packaging design, it was also mainly based on past experience and what has worked well with previous GPHE units. This led to many issues such as having packages that are not strong enough to withstand the GPHE units' weight or too narrow packages causing the units to tip over. To prevent this situation from occurring in the future, there is an urgent need to adopt and implement a packaging design methodology that is based on more reliable design tools such as numerical simulations and FEM tools. Goodwin and Young (2010) states that the use of such tools is important for high value product for which damages lead to significant losses of revenue. Goodwin and Young (2010) also states that advanced techniques such as drop tests, boundary damage tests, cushioning performance tests, top-load stacking tests and random vibration tests will enable the development of protective packages that ensure the products integrity and quality throughout the supply chain.

7.2 Identify missing packaging parameters

The data gathered during this project have not enabled the evaluation of the current packaging system against the identified supply chain requirements. In other words, the researchers have not been able to define whether the packaging has the required protective abilities, especially in respect to the shocks and humidity levels recorded. The obstacle to packaging evaluation was due to the fact that packaging design related data was not available. The missing design data relates for instance to the packaging compressive, bending and tensile strengths, as well as the packaging material resistance or reaction to moisture. This data must be defined in order to evaluate the performance of the current packaging systems. Once the evaluation made, Alfa Laval GPHE will be able to identify the packaging system characteristics that must be improved to achieve a more effective protection of products and consequently have less damages occur during shipment. The identification of such parameters can also be used to provide handling instructions for the external forwarders. One example can be the identification of the maximum top-load and stacking height allowed to prevent damages.

7.3 Standardize the packaging process

During the data gathering phase of this project, it was noticed that some of the packaging process procedures varies from one packaging team to another. This is suspected to be one of reasons that cause some GPHE units to detach from the skidbase during shipment and tip over. Therefore, it is important that the packaging process is standardized across the different packaging teams. This will help to identify the real reasons to why some units detach from the packaging bases during shipment. In addition, it will help to evaluate whether the current measures (e.g. number of straps and bolts) used to anchor the units to the packaging base are enough or if further measures must be taken.

7.4 Make the customer aware of the potential risks

As previously discussed, it is during the sales process where a decision about what packaging solution to use is made. In addition, many customers choose the cheaper packaging solutions instead of the most suitable for the shipment journey. Furthermore, it is currently unclear whether the sales person informs the potential client about the transport inherent risks. A suggestion to improve this situation is making it a required step, during the sales process, to inform the prospective client about all the potential risks that may arise during shipment. It is also suggested to use pictures documenting previous damages as a persuasion tool to encourage the client to choose the most protective packaging solution instead of the cheaper alternative. Other suggestions would be to make the packaging system selection an internal process. In other words, it will be the Alfa Laval's personnel that makes the decision about the adequate package to be used for the transport journey instead of the customer.

7.5 Transfer of knowledge

The sensor data indicated that high magnitude shocks occurred both inside the Alfa Laval facility and outside of it during external transport. However, the damage register indicates that most of the reported damages occurred during cargo shipment and outside the Alfa Laval facility. The damage claims during transport range between 30 and 50 claims per year. This can be explained by the difference in the number of handling operations inside and outside Alfa Laval. The frequency of high shocks is low inside the facility since, as previously discussed, there are mainly three operations inside Alfa Laval under which the packages are picked from the packing station, stored and picked again to be loaded. On the other hand, during external transport the frequency of high magnitude shocks is much higher due to vibrations in transport, shocks during change of transport mode, shocks during handling at ports and during unloading at the customer facility. Therefore, there is a clear need of knowledge transfer from Alfa Laval GPHE to the other forwarders involved. The knowledge transfer should be about the proper ways of handling packages and securing them to the truck bed or cargo container. Currently, cargo security instructions are not available for all products but mainly for the large size units. To ensure a better protection, it is suggested to develop cargo security instructions for all products. In addition, to tackle the language barrier between the various forwarders, it is suggested that the cargo safety instructions should contain mainly or only pictorial instruction instead of textual instructions. Another idea is to have safety instruction videos, which can be sent to the external transport providers prior to the pick-up or watched by the truck drivers before loading.

7.6 Redesign of all packages that have been problematic

As the researchers did not have full access to the customer complaints register due to confidentiality and have not been informed about all the damages that occurred in the past. The packaging design team must first examine the damage register and customer complaints. Then, they must identify the industrial packages that have not been well designed to suit the product (e.g. weak skidbases unable to withstand the product's weight) or the supply chain conditions (e.g. high humidity and shocks). These deficient industrial packages must urgently be redesigned to avoid the occurrence of damages in the future. The redesign of poorly designed packages is of a great importance, as the industrial package is the only component of the cargo shipping system that can be modified relatively easily to protect the cargo and reduce damage related loss of revenue (Idah et al. 2012; Goodwin and Young 2010).

7.7 New Storage Facility

The data gathered during this project indicated that some industrial packages are stored in an outdoor storage before being picked and loaded into the trucks for shipment. The outdoor storage causes the industrial packages, as well as the products to be in a direct contact with rainfall, snow, wind and water puddles. The sensors data indicated that the relative humidity during outdoor storage can reach 99%. Noteworthy that the duration of exposure to these climatic conditions varies greatly according to the time between storage and cargo pick up, which ranges from few hours to few days. The exposure to such climatic conditions can cause damages such as the wooden packaging to lose its strength and consistency leading to cracks in the package and the loosening of the straps holding the product to the skid base. Therefore, it is suggested to build a storage facility that can protect the packages and the packed products from damages or quality deterioration caused by the previously cited climatic conditions.

7.8 Further investigation into the internal Shocks

The sensor data indicated the frequent occurrence of intense shocks inside the Alfa Laval GPHE facility. The registered shocks have reached high magnitudes up to 13g force, which can create serious damages. However, the current sensor data does not indicate the exact operation(s) in which these intense shocks occur. Noteworthy the analysis of sensor data was done based on the assumption that after packing the product in the assembly line, it is directly moved to the storage facility and then picked it up and loaded to the truck bed. However, the cargo may have been again stored in one place and moved to another place. Therefore, it is suggested to conduct a further investigation about shocks inside Alfa Laval GPHE facility that will pinpoint exactly which operation(s) causes these high shocks.

7.9 Packaging lifecycle management and its governance model

In order to prevent the previously cited issues from occurring in the future, such as having a packaging design based solely on previous experience instead of a proper design methodology or having packages that are no longer suitable due to changes that occurred over time (e.g. product modifications, new transport routes or export requirements). It is suggested to adopt a packaging lifecycle management process that defines what the different lifecycle phases of a package are and what activities should be done in each of these phases. In addition, in order to ensure the effective adoption of the PLM process and the continuation of its execution in the future, a PLM governance model must be established. This governance model would define the various stakeholders involved and their respective tasks.

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