Northern Institute of Technology Management

Master Thesis

Transportation Optimization of EMEA Raw and Pack Materials Supply Chains

submitted by

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Declaration

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I, Volha Leusha (student of Masters Programme in Information and Communication Systems, Matriculation Number: 21043638, hereby swear that I single-handedly compiled this document. I did not make use of any other sources than those listed here. Furthermore I swear that this document was never handed in to another department in this or any deviated manner. Every passage referring to or quoted from another source is identifiable as such.

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Abstract

This thesis is about VFR (Vehicle Fill Rate) optimization for one of raw materials used in diaper production, namely, NWs (Nonwovens).

NWs are packed inside TUs (Transport Units) as cylindrical bundles and are considered to be relatively light materials, therefore the volume of TUs is filled before weight limit is achieved. Moreover, suppliers are utilizing all available height of TUs, leaving a small space between roof and top of NWs to perform loading and unloading procedures. Taking all stated into account, vehicle fill rate improvement possibility is checked for deck area based VFR.

Looking into deck area utilization and knowing that bundles in two-dimensional horizontal cut are circles, problem of deck area utilization improvement can be viewed as problem of optimal packing of equal circles inside a rectangle. For this problem a lot of research has already been done.

In this thesis simplified symmetrical model to solve this two-dimensional optimization problem is created. Model is symmetric due to manual truck loading. According to interviews with suppliers, nowadays deck area utilization of TUs is around 67% in average. However, according to created model, if to increase diameters of bundles from 1000mm to 1200mm- 1300mm there is a possibility to improve deck area utilization to approximately 78%.

This possibility is evaluated from supply chain point of view. The impact of increased diameter on supply chain is evaluated. For this purpose supply of NWs is presented, starting from production of NWs and ending with diaper production. Moreover, financial analysis of possible scenarios of project future is shown, and conclusions on possibility and profitability of investment is discussed.

Contents

List of Symbols

Abbreviations

AGM	Absorbent Gel Material
AQL	Acquisition Layer
BEL	Back Ear
BS	Back Sheet
CC	Core Cover
CF	Corporate Function
$ceil()$	Function that Rounds a Number Up to Integer
DL	Dusting Layer
$E2E$	End-to-End
$EMEA$	Europe, Middle East and Africa
FE	Front Ear
$floor()$	Function that Rounds a Number Down to Integer
GBS	Global Business Servide
GBU	Global Business Unit
$IBNW$	Inner Belt Nonwoven
MDO	Market Development Organization
MSM	Material Supply Management
$nsBE$	non-stretch Back Ear
NW	Nonwoven
$OBNW$	Outer Belt Nonwoven
RM	Raw Material
$P\&G$	Procter and Gamble
TS	TOP Sheet
TU	Transport Unit
VFR	Vehicle Fill Rate

Chapter 1

Introduction

Nowadays companies are more and more looking to shorten lead times and provide better services to customers in order to sustain competition. At the same time they neglect the fact that this may result in inefficient transportation of production output. This fact, together with increased interest in environmental problems (H. Aronsson, 2006, p.394), pushes governments to create polices in order to stimulate reduction of transport demand (by de-coupling), improve vehicle utilization, etc. The improvement of the situation is expected not only from transport companies, but from every company that influences the transportation of goods and *P&G* is not an exception.

1.1 Project Objective

Transportation optimization is an area where the management team of *P&G* has not been able to penetrate sufficiently. Holistic picture of the region is missing, making it difficult to benchmark across different raw materials, locations and suppliers.

The objective of the thesis is to analyze suppliers packing and shipping operations, created holistic reference database across raw materials, suppliers and *P&G* plants, and to choose a material for further analysis.

For this material analysis of supply chain is performed and a solution for VFR (vehicle fill rate) improvement is proposed. The impact of the solution on supply chain and *P&G* suppliers processes is investigated. Names of suppliers are not used in this thesis due to confidential reasons. For the same purpose, absolute forecasted values, mentioned in this thesis, do not match the reality. However, the relative values are kept on the same level to reflect the real picture.

1.2 Background Information

The organizational structure of *P&G* consists of GBUs (Global Business Units), Global Operations, GBS (Global Business Services) and CF (Corporate Functions) and is shown in Figure 1.1 (Procter&Gamble, 2013, p.24).

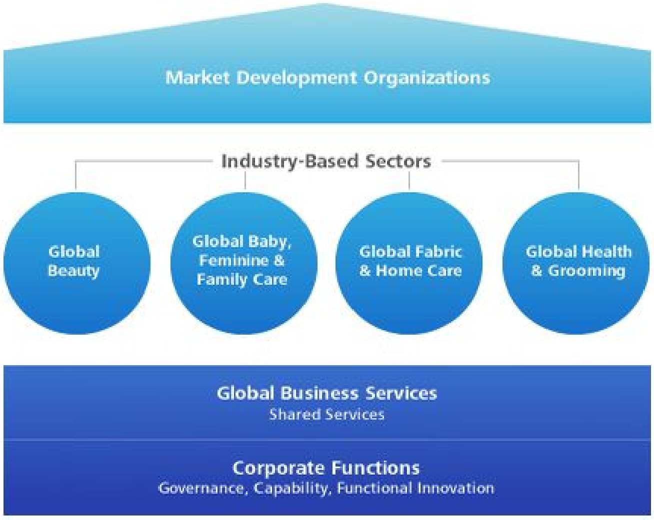

Figure 1.1: P&G Corporate Structure Procter&Gamble (2014)

The GBUs are divided into reportable industry-based segments. Net sales and brand compositions of this segments are shown in Figure 1.2. GBUs task is to develop overall brand strategy, new product upgrades and innovations and marketing plans (Procter&Gamble, 2013, p.24).

Reportable Segment	% of Net Sales*	% of Net Earnings*	GBUs (Categories)	Billion Dollar Brands
Beauty	24%	21%	Beauty Care (Antiperspirant and Deodorant, Cosmetics, Personal Cleansing, Skin Care); Hair Care and Color; Prestige (SK-II, Fragrances); Salon Professional	Head & Shoulders, Olay, Pantene, SK-II, Wella
Grooming	9%	16%	Shave Care (Blades and Razors, Pre- and Post-Shave Products); Braun and Appliances	Fusion, Gillette, Mach3, Prestobarba
Health Care	15%	17%	Feminine Care (Feminine Care, Incontinence); Oral Care (Toothbrush, Toothpaste, Other Oral Care); Personal Health Care (Gastrointestinal, Rapid Diagnostics, Respiratory, Other Personal Health Care, Vitamins/Minerals/Supplements)	Always, Crest, Oral-B, Vicks
Fabric Care and Home Care	32%	27%	Fabric Care (Bleach and Laundry Additives, Fabric Enhancers, Laundry Detergents); Home Care (Air Care, Dish Care, Surface Care); Personal Power (Batteries); Pet Care; Professional	Ace, Ariel, Dawn, Downy, Duracell, Febreze, Gain, Iams, Tide
Baby Care and Family Care	20%	19%	Baby Care (Baby Wipes, Diapers and Pants); Family Care (Paper Towels, Tissues, Toilet Paper)	Bounty, Charmin, Pampers

* Percent of net sales and net earnings from continuing operations for the year ended June 30, 2013 (excluding results held in Corporate).

Figure 1.2: P&G Business Segments (Procter&Gamble, 2013, p.24)

MDOs are location specific organizations and aim to understand consumers and retailers in specific markets. Using this information MDOs take innovations provided by GBUs and integrates them in different countries. P&G MDO distribution is shown in Figure 1.3.

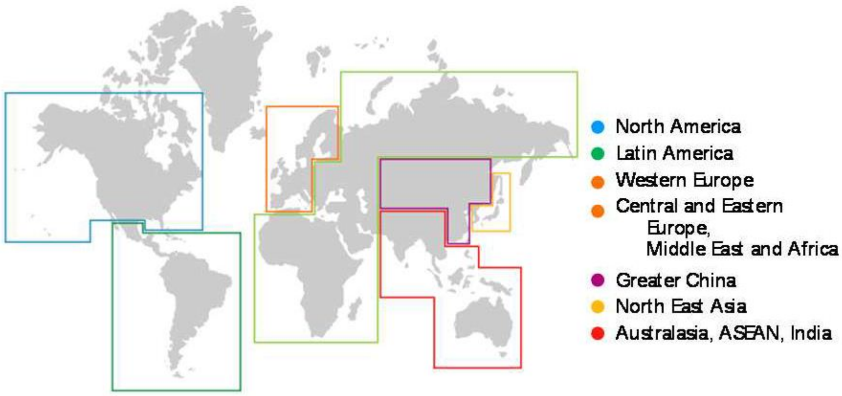

Figure 1.3: PG Market Development Organizations (P.Mishra, 2012, p.3)

GBS insures support services for other *P&G* organizations and CF provide functional innovation and capability improvement. This thesis is done in cooperation with *P&G* Baby Care GBU for EMEA MDO and is considered to be a cost saving project. As is shown in Figure 1.2 , Baby Care and Family Care has a share of 20% of net sales and 19% of net earnings for the year ended on June 30, 2013. This reflects the importance of this GBU for *P&G*. A big portion of total net earnings of Baby and Family Care belongs to diapers production.
To produce a diaper particular raw materials are needed, such as AGM (Absorbent Gel Material), NW (Nonwovens), Pulp, etc. Mishra in his thesis P.Mishra (2012), shows the importance of looking into improvement of RMs packing with the example of AGM (Absorbent Gel Material), stating that AGM alone accounts for 15% net spends, 5-10% of which falls to lot of transportation. As can be seen AGM takes a big portion of spends for RMs, however, there are other RMs that are important in diapers production. This finding motivates to look also into other material classes, looking for further savings opportunities.

1.3 Scope of Work

In this thesis optimization of VFR for one of the raw materials used in diaper production is done. Consequently, to build the base understanding of what is VFR and how it can be calculated and collected, the theory on this topic is presented in Chapter 2.

Understanding current transportation situation is critical for qualified optimization. Without having a deep look inside the logic of how containers and trucks are packed there is no possibility to propose a good solution. Therefore, interviews with suppliers are performed and database on VFR for different raw materials is created. This database is used for further calculations and analysis. Template of interviews is presented in Appendix C.

As the holistic picture of RMs supply chain across the region is missing, Chapter {RMChoice starts with an overview of all raw materials that are used in diaper productions. The distribution of demand for each of them is discussed, and the raw material, NW (nonwoven), is chosen for further analysis.

In Chapter 4 supply chain description for NWs is presented. It starts with an overview of different NWs types and their supply chain structure, and proceeds with supplier processes, transportation modes, and processes at P&G site. This is required to build reader understanding of the current situation with VFR, how it can be improved, and the impact on supply chain it will have.

As the next step, a proposal for VFR improvement is presented in Chapter 5. In this chapter, metrics to measure VFR rate for nonwoven materials are discussed. For deck area based VFR, the proposal is evaluated through modeling, and results are shown in Section 5.3. In Section 5.4 volume based VFR is discussed in greater detail.

As a necessary step of proposal evaluation financial analysis is presented in Chapter 6. Impact on different parts of supply chain is calculated. Moreover, financial analysis is performed for three possible scenarios of project future. This is explained in Section **??**. As additions to this chapter, Appendices A and B are included, where mathematical simulation model for deck area calculation and MatLab source code of this model can be found.

In the last chapter of this thesis, Chapter 7, summary and next steps are presented. In this chapter, conclusion and suggestions, based on performed analysis, are stated.

Chapter 2

Related Literature and Theory

Nowadays there is an increasing interest in the topic of environment pollution. As transportation is one of the major reason for environmental problems it gets a lot of attention in all levels of society, starting from government and environmental organizations and ending with transportation companies. Moreover, as a huge part of spending of production companies falls into transportation, to be competitive on the market, these companies also look into transportation optimization (H. Aronsson, 2006, p.394).

TU (Transport Unit) is a tangible resource that by itself is not helpful in competition between companies. The competitor can get the same type of truck or container. The key point to achieve a competitive advantage is to use combination of vehicles with other tangible and intangible resources, such as knowledge on empty running, advanced packing, experienced truck loaders, etc. (S.V. Hosseini, 2011, p.26)

Hosseini, in his study on fill rate in road freight transport S.V. Hosseini (2011) provides a comprehensive literature review on approaches to measure freight performance. Some of them are shortly described in Section 2.1.

2.1 Measurement of Transport Performance

According to A.McKinnon (1999), the transport performance can be measured with the help of five indicators (S.V. Hosseini, 2011, p.18):

1. Vehicle fill rates: weight utilization, pallet numbers in TU, etc.

2. Empty running: how many kilometers truck travels empty.

3. Time utilization: unloading, loading, waiting time, maintenance, etc.

4. Schedule deviations.

5. Fuel efficiency: equipment and motor power utilization.

Duma, in L.Duma (1999), introduces seven benchmarking measures for transportation efficiency (S.V. Hosseini, 2011, p.19):

1. Transport distance.
2. TUs used in lanes.
3. Number of vehicles.
4. Distance of transportation.
5. Operation time.
6. Tariff revenue.
7. Capacity.

Already from the two approaches described above it can be concluded that freight performance is complicated to measure. Not only utilization of space inside containers should be calculated and optimized, but also other aspects should be taken into account. It can happen that a negative impact from changes in supply chain outweigh the positive impact from better trucks utilization.
There can be different reasons for incomplete utilization of TUs. McKinnon and Edvards A.McKinnon (2010) state that this reasons can be following (S.V. Hosseini, 2011, p.29):

1. Market-related: fluctuations in market demands can cause deviations in transportation volumes.
2. Regulatory: weight and size limitations for TU, allowed timing for deliveries and road utilization, and safety.
3. Inter-functional: uncertainty, unreliability, low support and other restrictions from other departments
4. Infrastructural: reasons that arise due to limitations in capacity of transport network.
5. Equipment-related: appears because of limitation in equipment. Equipment can be of different types, namely handling, production, warehousing, vehicle, etc.

2.2 Vehicle Fill Rate

According to (S.V. Hosseini, 2011, p.26) there is no universal definition of VFR as well as model to calculate it. Approach to VFR calculation is situation specific. Moreover, fill rate is not the only metric to measure TU utilization. There are such parameters as empty running or waiting, loading and unloading efficiency, etc. Therefore, even optimized fill rate is not always the optimal solution because of other restrictions.
Another problem in VFR measurement is that it can be measured using different basic parameters. Hosseini and Shirani, in there work about fill rate in road freight transport (S.V. Hosseini, 2011, p.36-39), provide an overview of different methods to calculate VFR, namely ton-km, weight based, volume based, deck area, and pallet based VFR. The short summary on each of them is presented in this section.

Ton-km

The formula to calculate ton-km fill rate is presented below:

$$VFR_{ton-km} = \frac{actual\,ton - km\,moved}{maximum\,ton - km\,that\,can\,be\,moved}. \tag{2.1}$$

Weight based VFR

The difference between ton-km and weight based VFR is that the first can vary during the trip whereas in the second it is assumed that weight is constant in one trip.
It can be measured with formula:

$$VFR_{weight} = \frac{actual\,weight\,of\,freight\,moved}{maximum\,weight\,of\,freight\,that\,can\,be\,moved}. \tag{2.2}$$

Weight based VFR is easy to measure, therefore it is used by a lot of companies. However, this VFR is not always the most applicable one as for a lot of materials volume and deck area is utilized before the weight is filled to maximum.

Volume based VFR

The volume vehicle utilization is a problematic parameter to benchmark and measure. First of all there is a very low data available on space utilization of TUs (A.McKinnon, 2000, p.27) making it difficult to compare available company data with industry data. Moreover, the collection of this VFR is not easy because of difficulties in measurement of accurate volume of products inside trucks due to abnormal shapes of packing. For, example, if a raw material is placed on pallets it is not always clear if width and length of pallet should be considered or width and length of material itself stacked on the pallet. The general formula to calculate volume based VFR is presented below:

$$VFR_{volume} = \frac{utilized\,volume\,of\,TU}{total\,volume\,of\,TU}. \tag{2.3}$$

Despite all the limitations volume based fill rate is primary parameter to take into account in a lot of cases. Especially, it becomes important in recent decades. According to McKinnon (A.McKinnon, 2010, p.5), decrease of freight density due to intensive use of plastic instead of wood and metal, together with increase of allowed weight for moving TUs, shift the importance from weight based fill rate towards volume based VFR.

Deck Area based VFR

Deck area based VFR can be calculated with formula:

$$VFR_{deck-area} = \frac{covered\,by\,freight\,deck\,area}{maximum\,number\,of\,pallets\,that\,can\,be\,put\,in\,deck}. \tag{2.4}$$

This vehicle fill rate is not the favorite among researches. It is constrained by TU size and is higher than volume based VFR as can be viewed as two-dimensional picture of volume fill rate. However, there is still some room for improvement of this rate depending on the situation (S.V. Hosseini, 2011, p.39).

Pallet based VFR

This VFR is known in literature as a particular case of volume based fill rate. It describes VFR for freight that is transported on pallets and can be calculated dividing actual number of pallets in deck by maximum number that can be placed in deck of TU:

$$VFR_{pallet} = \frac{number\,of\,pallets\,in\,deck}{total\,deck\,area\,of\,TU}. \tag{2.5}$$

2.3 Vehicle Fill Rate Increase

Some suggestions of how the VFR can be improved is provided in literature. In (S.V. Hosseini, 2011, p.44-45) some of the approaches are summarized from different literature sources. Promising solutions are presented below in short description:

1. Improve packing of freight leaving less air between units.

2. Change dimensions and capabilities of handling equipment, production equipment and warehouses.

3. Use IT solutions such as computer schedules and telematics.

4. Use double-deck TUs or stacking (one unit of freight placed on top of other unit).

5. Use of load consolidation more often.

6. Use transport units that are more suitable for particular types of freight.

7. Increase volume of goods moved by one TU by less frequent orders.

Chapter 3

Raw Material Choice

In this chapter the overview of raw material classes used in production of diapers is presented. The packing of each raw material class and the complexity of supply chains is analyzed.
In Section 3.2 raw material for further investigations is chosen taking into account forecasted volume for next year, complexity of supply chain network and possibility to reapply the strategy for other materials.

3.1 Analysis of Raw Material Classes

To understand the variety of raw materials and there possible packaging strategy there is a need to understand production process of diapers. The production process is divided into several stages. At each stage the production line is supplied with different raw materials to produce the output. The output of previous stage, together with other raw materials, is an input of subsequent stage. As is shown in Figure 3.1 a diaper consists of nonwovens, BEL (back ear), AQL (acquisition layer), BS film (back sheet film), absorbent materials, glues, elastics, lotions, etc. As the ready diaper needs to be packed, additionally such raw materials as flexible bags or carton boxes (corrugated) are used.

Nonwovens are supplied to production line in rolls and are unwinded to form different layers of diaper, such as back sheet, front sheet, etc. Between these layers absorbent materials are placed. Layers are connected with each other with adhesives (or glues). Elastics, tapes and hooks are needed to form the shape of pant, to make it possible for a baby to wear the diaper.
Raw materials are supplied in special packages to make supply process easy, safe and efficient. As is shown in Figure 3.2, raw materials packaging in *P&G* has several different

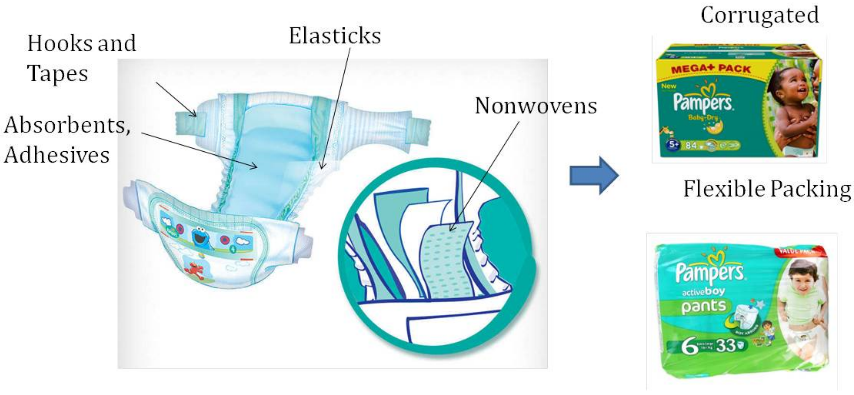

Figure 3.1: Raw Materials Used in Diaper Production

types: bundles, plastic boxes, bags, carton boxes, etc. Nonwovens, BELs, AQLs and BS films are supplied as bundles of cylindrical shape, namely several rolls are placed on each other and tied together with foil that can be placed on pallets or on carton sheet of half centimeter width. Adhesives and flexible packing are supplied in special plastic boxes of standard dimensions. Tapes, hooks and elastics are packed inside carton boxes. The packing pattern of material inside this boxes, dimensions and types of these boxes differ from material to material and can not be viewed as universal.

Figure 3.2: Raw Materials Packaging in *P&G*

Absorbent materials are packed depending on material type. AGM (Absorbent Gelling Material) is delivered in big bags. Pulp is covered with plastic foil and tied with black

rings. Lotions and other chemicals are delivered usually in special containers, however, packing can also be of other types. Corrugated are stacked on pallets in disassembled way as layers and are placed on pallets on top of each other.
Absorbent materials are left out of scope in this thesis as it has been analyzed already in other research paper of Mishra P.Mishra (2012). Moreover, due to localization of supply chain for corrugated materials and low volumes of chemicals, flexible bags, and elastics they are also left out of analysis.

3.2 Choice of Raw Material

According to primary analysis in previous section the scope of raw materials benchmarking is decreased to nonwovens, AQLs, BS films, BELs, adhesives, tapes, hooks and elastic. The basic measurement unit to calculate amount of material needed for production of diapers are $Msqm$ and $tons$. Some of the raw materials are counted only in $tons$ (such as AQLs) or in $Msqm$ (such as BELs). Majority of materials are measured in both metrics. However, the measurement in $tons$ and $Msqm$ is not always applicable for VFR evaluation, therefore, the average amount of material in m^3 was evaluated and summarized in Figure 3.3.

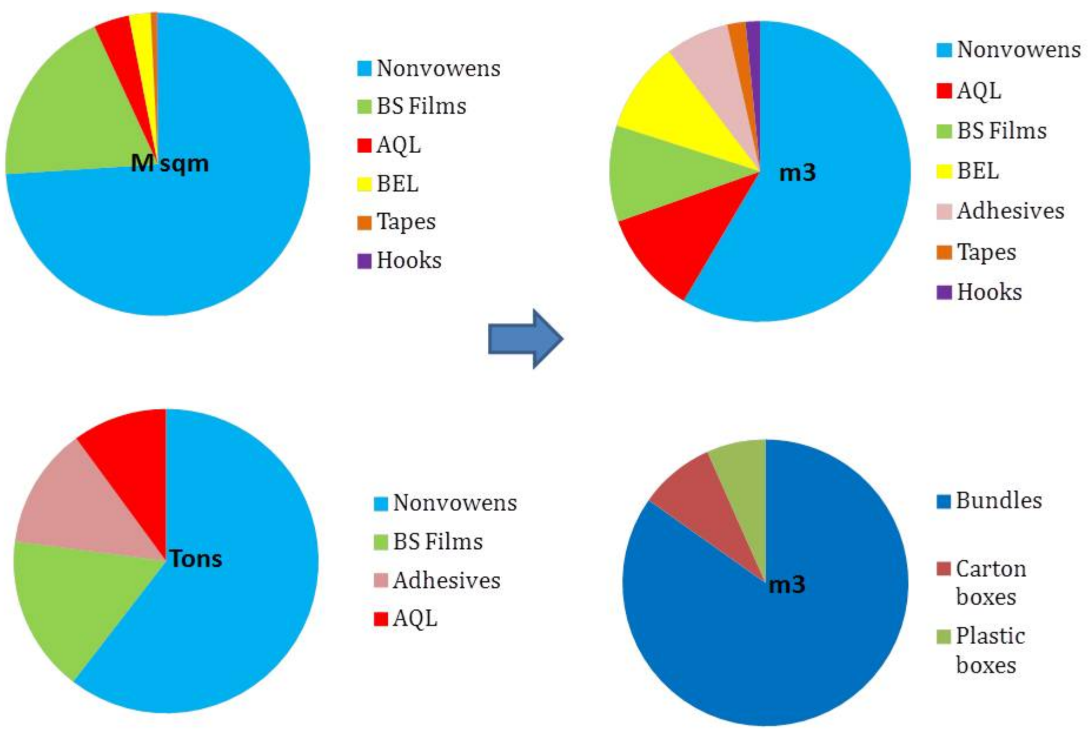

Figure 3.3: Raw Materials Volume Distribution

From the Figure it can be stated that nonwovens have the biggest volume in m^3 from all materials under observation. Moreover, nonwovens are packed in cylindrical bundles similar to most of materials in scope. Consequently, the approach and solution of VFR improvement can be reapplied for other material types packed in bundles, making nonwovens an attractive option for further analysis.

Chapter 4

Supply Chain Analysis for Nonwovens

In the previous chapter it was decided to use nonwovens for further analysis. Consequently, this chapter provides more detailed background on this specific material class.
According to S. Chopra (2007), the total supply chain profitability can be viewed as a summation of cost reductions in each separate part of supply chain network (P.Mishra, 2012, p.8). Therefore, it is important to take into account the complete supply network of nonwoven material, starting from production process of nonwovens and ending with production process of diapers. The supply chain overview for nonwovens is presented in Figure 4.1.

Figure 4.1: Supply Route for Nonwovens

First section of this chapter is about classification of nonwovens and is presented in order to give the reader an idea of NW types and distribution.
Section 4.2 provides an overview of the supply chain network. It targets to show complexity of the network and amount and structure of the supply lanes.
Section 4.3 gives a short overview of processes that are performed on supplier side, namely production of NWs, their packing and truck loading. In Section 4.4 explanation about packing and transportation of NWs is given. Last section of this chapter explains pro-

cesses that are performed with NWs at *P&G* side of supply chain, namely unloading, warehousing, line loading and production process of diapers, the last step in RMs supply.

4.1 Types of Nonwovens

According to (Standard, 1988, abstract) nonwovens are materials that consist of randomly oriented fibers bonded by friction and/or cohesion and/or adhesion. They can be in the shape of a sheet or a web. Nonwovens of diapers are divided into types depending on the function they perform: cuff, CC(Core Cover), BS(back Sheet) , TS(Top Sheet), DL(Dusting Layer), FE(Front Ear), ns BE(non-stretch Back Ear), IBNW(Inner Belt Nonwoven), and OBNW(Outer Belt Nonwoven), and are used for variety of task, starting from forming the diaper layers and ending with prevention of leakage and softness perception. Nonwoven material is winded on the core forming a roll as shown in Figure 4.2. The core, on which the material is wrapped around, and diameter of the resulting roll can be different depending on material types, as is shown in Table 4.1.

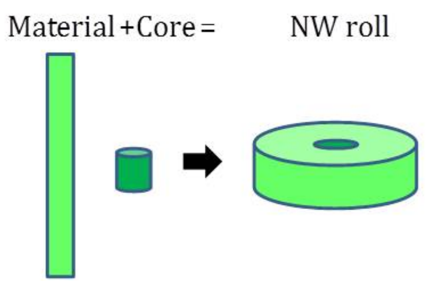

Figure 4.2: Roll Composition of Nonwovens

Table 4.1: Core and Roll Diameter for Different Types of Nonwovens

Types of Nonwovens	Core Diameter, mm	Roll Diameter, mm
CC, Cuff	76,2	1000 (+10/-25)
DL, TS	152,4	1070 (+10/-25)
BS, ns BS, FE	152,4	1000 (+10/-25)

The distribution of $Msqm$ of forecasted demands for next one year for nonwovens is shown in Figure 4.3. The figure shows that the volume of needed nonwovens is approximately the same for all types of nonwovens, except FE, ns BE, IBNW and OBNW. It happens because this particular types of nonwovens are either used for only specific low volume product types (as IBNW, OBNW, and ns BE) or are required in diaper only in small portions (as FE). This means that from supply point of view each NW type should be supplied to each location with exception of IBNW, OBNW, and ns BE.

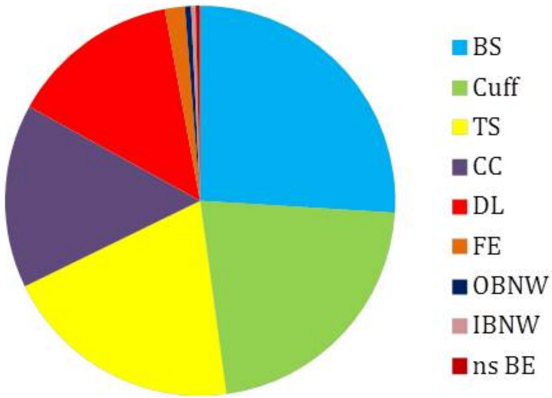

Figure 4.3: Distribution of $Msqm$ of Forecasted for Next Eightenn Months Types of Nonwovens

4.2 Nonwovens Supply Chain Overview

The target of this thesis is not to restructure the supply network, making it possible to exclude some suppliers from the network or find other closer suppliers, but to benchmark transportation packing across suppliers and propose a solution for VFR optimization and standardization. However, regardless to this, supply chain structure is important to be looked at in order to understand what assumptions can be made in future analysis.

Nonwovens supply chain of *P&G* for EMEA region is very complex structure. In total there are sixty three active lanes with ten suppliers and eleven *P&G* Baby Care plants. Some of suppliers have several locations resulting in a total of fourteen supply locations. Table 4.2 shows which nonwovens types are produced by which supplier and how many *P&G* locations are supplied by each of them. Some materials can only be produced by one or several suppliers (for example ns BE by Supplier 4) and, therefore, this supplier supplies all eleven EMEA plants.

Demand versus supply picture of *P&G* nonwovens for EMEA region is shown in Figure 4.4. The picture is based on one year forecast starting from 2014. From the image it can be seen that suppliers are mostly located in EMEA region except one supplier that is located in US. Even though it looks illogical from transportation point of view to have this supplier in EMEA supply chain, the supplier produces a specific material that other suppliers are not qualified to produce. Namely, BS with special specifications. Therefore, it is difficult to eliminate this supplier from supply chain.

Table 4.2: Overview of *PG* Suppliers

	Number of *P&G* locations	Number of supplier locations	Types of Nonwovens
Supplier 1	9	2	BS, CC, Cuff, DL, TS
Supplier 2	7	2	BS, Cuff, TS
Supplier 3	5	1	BS, CC, Cuff, DL, IBNW, OBNW
Supplier 4	11	1	BS, Cuff, FE, ns BE, OBNW, TS
Supplier 5	5	1	BS, Cuff, TS
Supplier 6	7	2	FE, TS
Supplier 7	6	2	CC, DL, BS, Cuff, TS
Supplier 8	5	1	CC, DL, TS
Supplier 9	4	1	BS
Supplier 10	6	1	BS, CC, DL

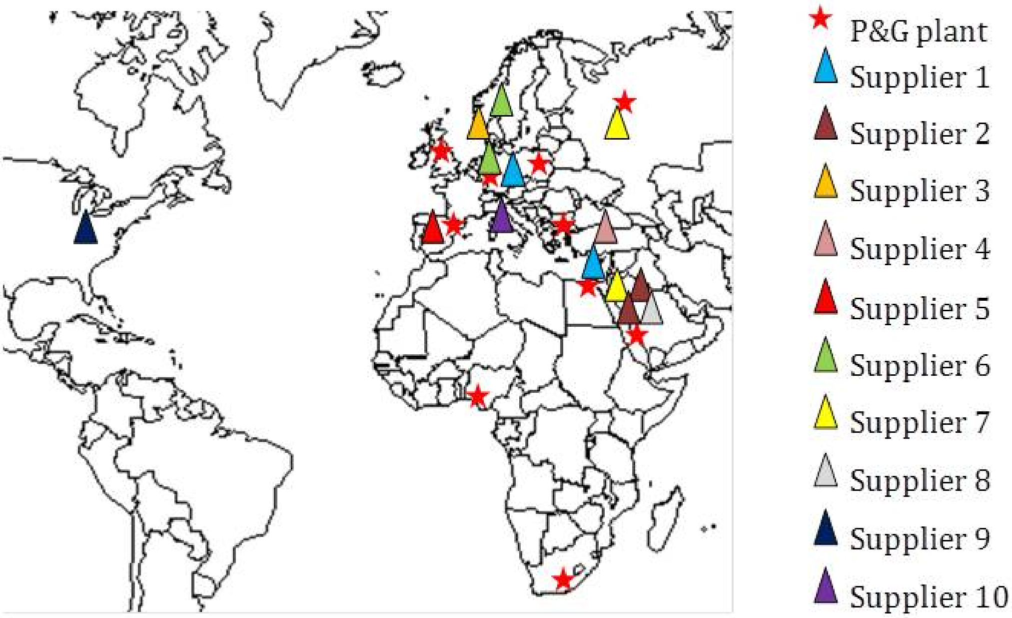

Figure 4.4: Demand versus Supply Picture of *P&G* Nonwovens for EMEA

The distribution of forecasted volume across suppliers is shown in Figure 4.5, from which it can be seen that three biggest suppliers produce more than a half of total nonwovens volume, making these suppliers specifically important for analysis.

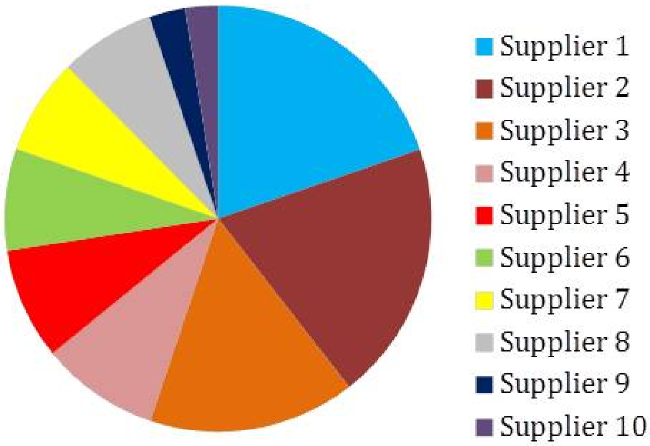

Figure 4.5: Distribution of Forecasted Volume between Suppliers

4.3 Processes on Supplier Site

In this section supply chain for NWs on supplier site is analyzed in detail. Figure 4.6 is an extension of Figure 4.1.

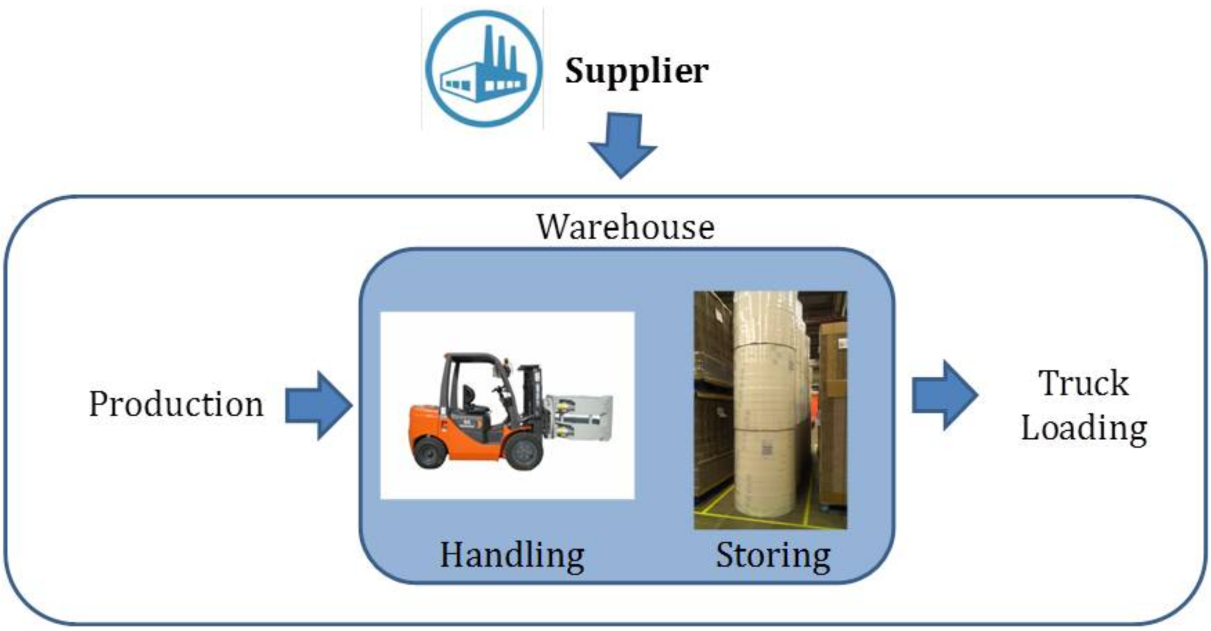

Figure 4.6: Processes on Supplier Site

It can be seen from this figure that on supplier site following processes take place: production of nonwovens, warehousing, packing, loading into trucks or containers, etc. All these aspects are important to take into account proposing a solution on VFR improvement. If solution means modifications in packing or dimensions of raw material it can negatively or positively affect the highlighted processes.

Production Process of NWs

There is no need to go into deep details about production process of NWs in this thesis, however, it should be stated that there is a limitation on roll diameter and weight due to equipment used in NWs production. From interviews with suppliers it is discovered that they can produce either up to 1200mm or up to 1500mm diameters of rolls depending on the supplier.

Warehousing

After NW is wrapped as a roll, rolls are placed on each other and tied with foil in shape of cylindrical bundle as is shown in Figure 4.7.

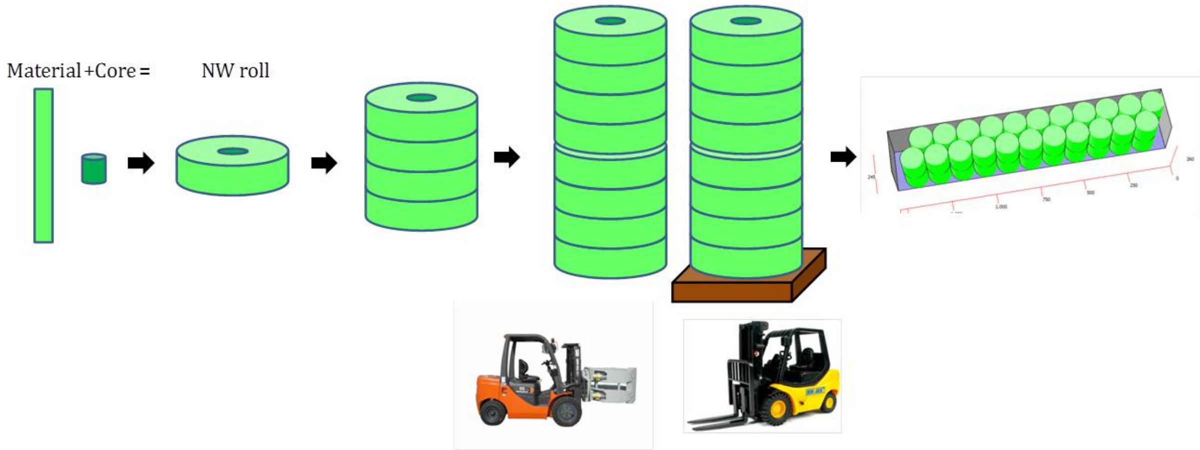

Figure 4.7: Packing of Nonwovens

These bundles are usually placed in warehouse before being transported to *P&G* location. In warehouse RMs can be stored in racks or on the floor. As Mishra mentioned in (P.Mishra, 2012, p.20), in case of racks, warehouse storage place is utilized better, however, there is no limitation on dimension and weight of raw material if the material is stored on the floor. In case when racks are used such limitations appear. This happens because racks are constructed of rails that have fixed distance between neighboring rails. Moreover, the weight that these rails can handle is also limited. Most of the suppliers stated that in their warehouses they store bundles up to 1200mm in diameter. Consequently, 1200mm can be for sure stored without any modifications in design of racks. For higher diameters this possibility should be further checked with tests.
Bundles are usually handled with clamp trucks. Sometimes they are placed on pallet. In this cases a fork lift needs to be used for handling. The usage of pallets in packing for particular lane results from the infrastructure that this lane has, namely warehousing and internal transportation of supplier and *P&G* plant. From interview with suppliers it is concluded that only three lanes use pallets for transportation. This is a very small

portion of all the EMEA NWs lanes. Thus, materials supplied on pallets are excluded from further analysis.

Packing and Truck Loading

Bundles are usually stacked in two and placed inside trucks with clamp trucks or fork lifts. Number of rolls in one bundle is not standard. The width of rolls is a variable that depends on diaper product type. Supplier decides on the number of rolls in one stack (two bundles) dependent on roll width and height of truck or container used. The logic is to fill the height as tight as possible, still leaving some place between the roof and top of the stack in order to make loading and unloading possible. Namely, a clamp truck or a fork lift drives inside the truck, with one stack of bundles, raised several cm above the floor, and leave it on the floor of a TU.
Sometimes bundles in one stack have same number of rolls, but not always. The upper bundle can have one roll less in case there is not enough place to put one more roll due to height limitations of TU. Number of bundles on deck is dependent on roll diameter and truck or container deck dimensions. The bigger the diameter the lesser the number or rolls the can be filled inside the same deck area. Also, in case of bigger deck area, more rolls of the same diameter can be put in the deck.
In Figure 4.8 the loading procedure is shown. After a roll is placed on the floor of TU, to free the roll, the distance between clamps should be slightly bigger than roll diameter. This puts some constraints on how bundles can be placed inside truck or container. As is shown in Figure 4.9, in case when clamp truck is used, there are some specific cases when loading and unloading procedures are not possible.

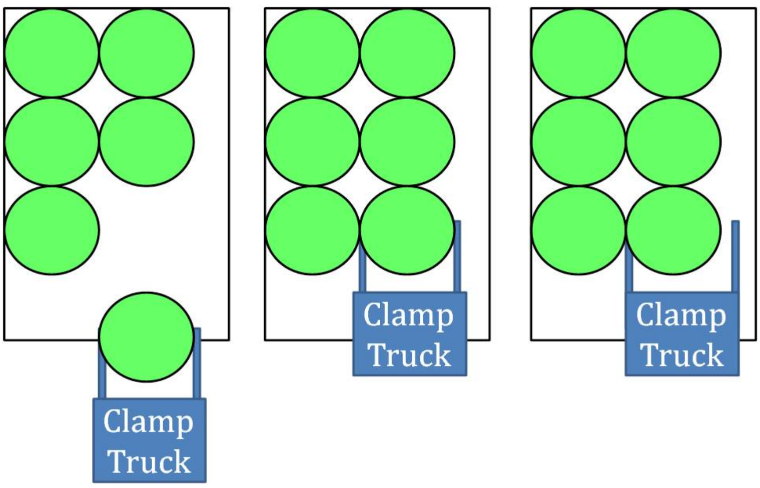

Figure 4.8: Loading Procedure for NWs inside TUs

In case when fork lift is used for loading and unloading the fork lift travels inside the

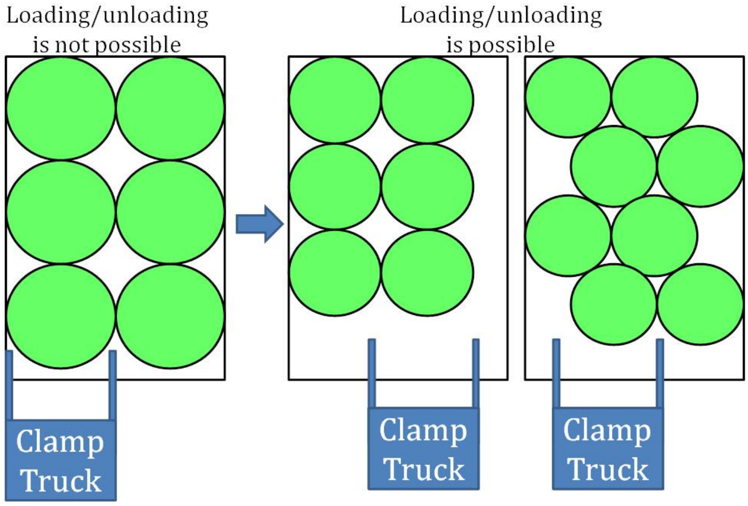

Figure 4.9: Special Case Blocking Unloading

truck and leaves bundles on the floor. Consequently, no place limitation between bundles in deck is required. The only limitation is to have enough place between roof of TU and top of bundle, so that the bundle can be raised above the floor.

4.4 Transportation of NWs

Nonwovens are delivered to *P&G* plants using ether trucks or containers. Containers are used for intermodal transportation, meaning that a cargo is transported to the target place by a sequence of at least two transportation modes with usage of intermodal terminals (C. Barnhard, 2007, p.467). Namely, *P&G* containers are first delivered from supplier location to the port with trucks. In the port they are placed on ships using cranes and transported as a sea freight. When containers reach destination ports, after custom clearance, they are placed again on trucks and delivered to *P&G* plant by road (P.Mishra, 2012, p.9).

Information on transportation modes for particular lanes was collected from suppliers and it is found that out of sixty three active lanes thirty three lanes are using pure truck transportation and thirty lanes are operating using intermodal transportation.

Moreover, it is discovered that there is no preferred option on container and trucks type used. Different suppliers can use truck and containers of different dimensions, starting with 40' ISO container, Euro trucks and ending with 40' ISO HC (High Cube) container and Jumbo trucks.

4.5 Processes on *P&G* Site

Processes on *P&G* site are shown in Figure 4.10. Processes are very similar to processes at supplier site. Below, all stages of this processes are discussed in details.

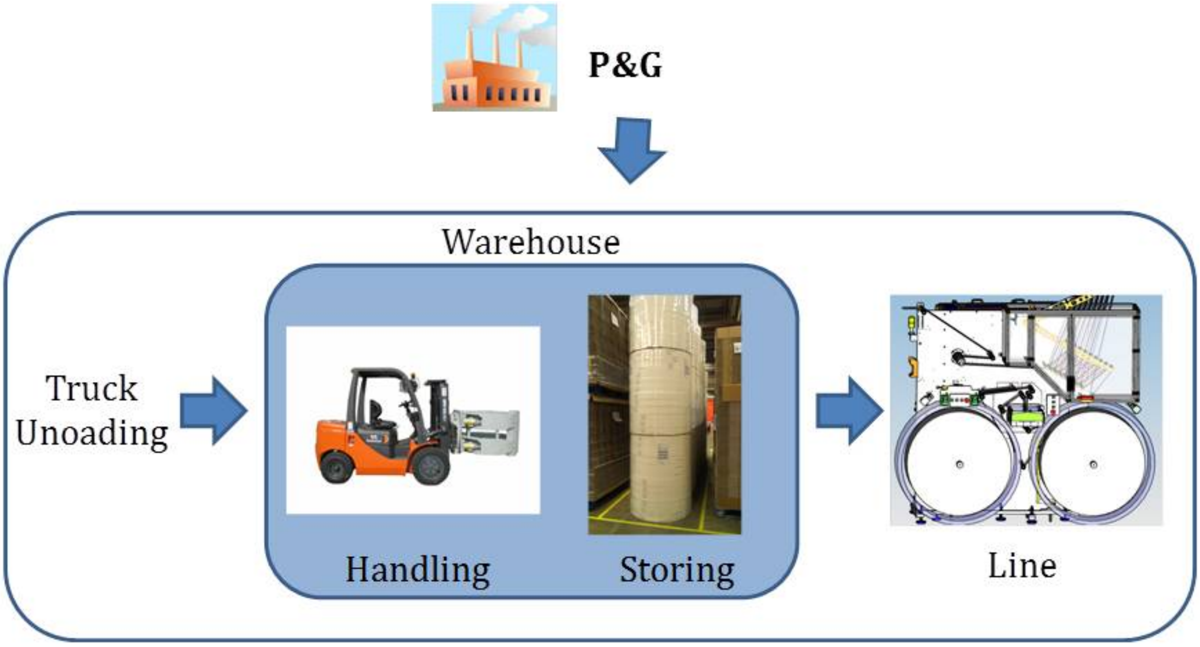

Figure 4.10: Processes on *P&G* Site

Truck Unloading

Unloading procedure has the same logic as loading procedure. Fork lift or clamp truck travels inside the TU and takes the outer stack of bundles out. When clamp truck is moving inside TU the distance between clumps is slightly bigger than roll diameter. When two clamps reach middle of the bundle, clamps are moved closer to each other to assure that they hold the bundle securely. Unloading procedure is shown in Figure 4.11. The limitations on the space between neighboring bundles inside TUs is the same as is described in Section 4.3.

The bundle that is taken out from the TU is placed on trailers that are transported to warehouse where the bundles are stored. The unloading procedure is performed by two truck loaders. One of them is unloading bundles from truck, placing them on a free trailer, and reading product codes. Second truck loader transports filled trailers to the warehouse. In warehouse he unloads bundles and puts them on the floor in stack of several bundles, from three to five. After this procedure is performed, second truck loader travels back to unloading area.

The process performed by the second truck loader is the bottleneck of unloading process as it takes more time to travel to warehouse, unload bundles and drive back than to

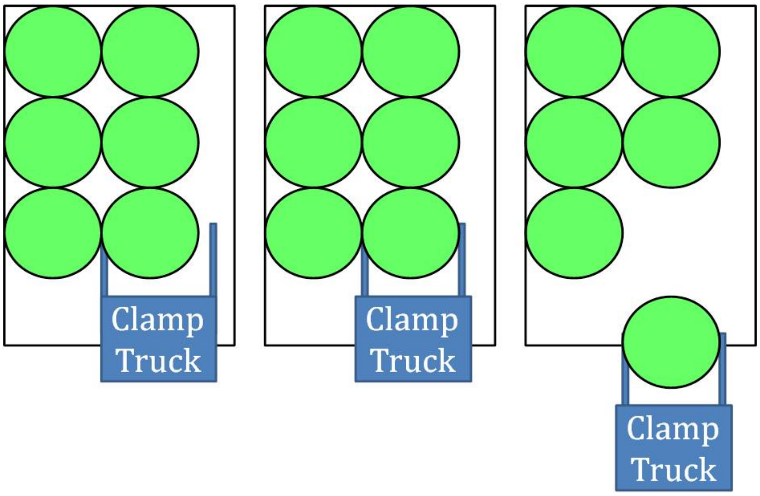

Figure 4.11: Unoading Procedure for NWs from TUs

unload bundles from TU and place them on empty trailers.
The overall timing of this procedure is not standard for different plants as size of trailer and distance from unloading area to the place in warehouse, where bundles are stored, can vary. Moreover, for different TU and types of NWs there can be different number of bundles in the deck.
Five independent measures of unloading times are done with different unloading teams to understand how long the unloading of one truck can take. Tests are performed for one of *P&G* location in EMEA. It is assumed that other plants have the same unloading time. In Table 4.3 the summary of test is shown.

Table 4.3: Tests Results for Unloading Timing

Procedure	Needed time, sec
Truck unloading /per stack	40
Code reading/ stack	15
Unload-warehouse per trailer	550

Knowing that second truck loader is a bottleneck it can be stated that only first trailer loading and code reading should be taken into account. Consequently, trailers will be loaded faster than the time required for the trailer driver to pick them up and deliver to the warehouse. According to this, the total time of unloading procedure is calculated for different TUs using formula

$$t_{total} = t_{truck\_unload} n_{trailer} + t_{code} n_{trailer} + t_{warehouse} ceil(\frac{n_{TU}}{n_{trailer}}), \tag{4.1}$$

where t_{truck_unload} is the time for one stack of bundles to be unloaded, $n_{trailer}$ is the maximum number of stacks of bundles that can be placed on one trailer, n_{TU} is the number of stacks of bundles in one TU, t_{code} is the time needed to read code of one stack of bundles, $t_{warehouse}$ is the time needed for one trailer to drive to warehouse, be unloaded and come back to unloading area, and $ceil()$ is the function that rounds a number up to higher integer.

Table 4.4: Total Unloading Time for Different TUs and NWs

Type of Transport Unit	Bundles in Deck (1000mm NW)	Bundles in Deck (1070mm NW)
40' Container	24	22
40' HC Container	24	22
Euro truck	29	25
Jumbo truck	32	28
Type of Transport Unit	**Unloading Time (1000mm NW) sec**	**Unloading Time (1070mm NW) sec**
40' Container	2585	2585
40' HC Container	2585	2585
Euro truck	3135	2585
Jumbo truck	3135	2585

Summary of results is presented in Table 4.4. It can be seen from the table that together with decrease in truck dimensions and increase in roll diameter unloading time decreases. It happens because the number of bundles in deck decreases. However, in case of slight difference in number of bundles ,the time needed for unloading remains the same because there is not decrease in the number of trailers driving to warehouse. The only difference is that the trailer drives half empty.

Warehousing

As was mentioned in Section 4.3, warehousing operations are divided into handling and storage. Most of *P&G* plants have possibility to use clamp trucks for handling. As was stated above, only three NW lanes use pallets and, consequently, fork lifts. According to (P.Mishra, 2012, p.19) handling equipment of *P&G* can lift loads up to 1200kg, however, the availability of this equipment is an open question. There are more than fifty different types of clamp and fork trucks used for internal transportation in P&G. All they have different allowed capacity. Therefore, the question about max weight and diameter that

clamp trucks of *P&G* can lift, and how the distribution of this trucks for RMs handling need to be restructured, is a question for further analysis.
In *P&G* warehouses NWs are mostly stored on floor making limitations on maximum weight and dimensions of NWs not applicable in this case.

Line Loading and Production Process of Diaper

As each type of nonwovens has a particular task and represents one of the layers that forms a diaper, it enters the production process at a particular location and is assigned to special unwinding equipment. This unwinding equipment is placed near production line and is used to put nonwovens into production process on the same speed and with particular tension, so that there is a constant material feed into the production process. This is shown in Figure 4.12.

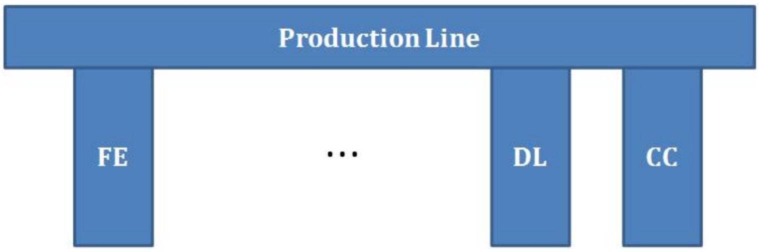

Figure 4.12: Production Line Feeding with Nonwovens

Each unwinding equipment holds two rolls of NWs at a time as is shown in Figure 4.13. As can be seen from the figure, rolls are placed near each other on handlers. The distance limitation between these handlers and between both of them and the floor, does not allow rolls bigger than 1140mm in diameter. Otherwise, the rolls touch the floor and overlap with each other.

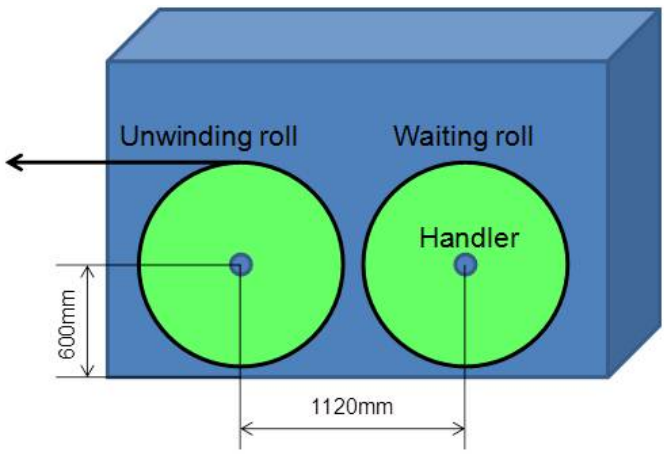

Figure 4.13: Nonwovens Line Feeding Equipment

The process of line loading is the following. At a steady state one of the rolls is running into production line and the other roll is waiting. As soon as the first roll is finished, equipment automatically start to unwind the second roll. When it happens, the core and remaining material of the first roll is removed by an operator from the handler and substituted with a new roll. This procedure is time demanding and takes a lot of manpower. The average effort of operator in minutes per day for line feeding with most important NWs is shown in Figure 4.14. This data is calculated using an available *P&G* model.

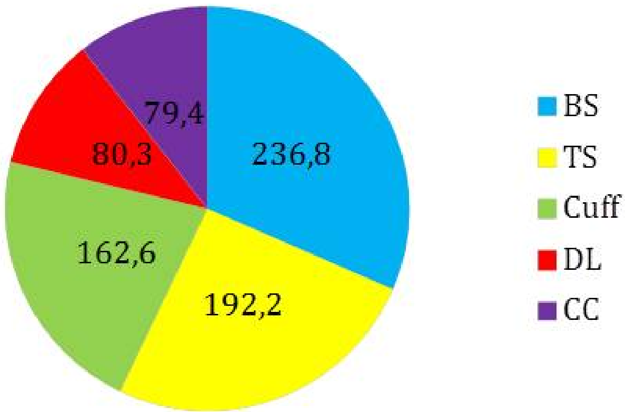

Figure 4.14: Average Effort of Operator in Minutes per Day for NWs line Feeding

Chapter 5

Proposal for VFR Improvement

As stated in Chapter 2, there are several approaches to measure VFR that can be applicable in different cases. Consequently, this chapter starts with matching the theory about vehicle fill measurement with realistic situation for NWs and follows with deeper analysis of VFR metrics that are chosen for further optimization.

5.1 VFR for Nonwovens

In order to understand the best approach to measure VFR for nonwovens there is a need to look deeper into nonwoven specifications. Nonwoven is a relatively light material. The weight of one roll can be calculated as

$$weight_{roll} = l * w * g, \tag{5.1}$$

where l is length of material in one roll in mm, w is width of roll in mm, and g is grams per m^2.

All this specifications are fixed for each particular material type, with low deviations (due to supplier process) that can be neglected in current analysis.

By multiplying the average weight of one roll with the average number of rolls in one truck it can be concluded that the weight of material in one 40' ISO container is approximately 9 tons and for euro trucks is approximately 11 tons (around 61% for volume utilization of container and truck). Weight limitations are different for different sizes of transportation units (A.McKinnon, 1996, p.12). Moreover, they can differ locally. For example, for regulations on payload weight and distribution of load, different governing regulation for shipment can be applicable depending on lane localization (P.Mishra, 2012, p.9). According to McKinnon, (A.McKinnon, 2000, p.28), the limit of weight load for EU cross-border

transportation is 40 tons. For inside-border transportation the limit varies from 40 to 60 tons.
However, the weight of transport vehicle itself and how much load it can transport should also be taken into account. For instance, DHL writes in there load specifications for euro trucks that up to 24 tons can be loaded DHL (2014). 11 tons, as calculated above, are way below from this number.
In this thesis it is assumed that weight is constant in one trip. This assumption excludes the necessity to look into ton-km based VFR. Another important aspect is that the demand of NWs is of high volume and transportation units are usually fully filled with NWs with no other material inside the trucks. This shows that the volume of truck is filled before the weight limit can be achieved.
The volume based VFR can be found by dividing volume transported in a truck by volume of maximum available volume of TU. If to assume that TU can be substituted, a solution can be to improve the VFR by changing random smaller trucks to bigger trucks, thus increasing the volume of goods moved by one TU and hence less frequent orders. The average VFR for current supply chain is 49% under the assumption that all random trucks are substituted with Jumbo trucks (truck with two trailers) and all containers are substituted with 40' HC ISO containers. However, the impact on inventory should be taken into account as more material will be delivered in one order. Moreover, transportation cost for bigger trucks and containers can be higher, decreasing savings.
Assuming that same trucks are used for transportation as are used today, volume based VFR , that is 61%, is not very useful in this case as the logic to put maximum number of rolls in one stack is already used by all NW suppliers. The only opportunity for improvement is to exclude pallets from lanes where they are used and put one more roll on top of the stack. However, this is applicable only for rolls that have thickness smaller or comparable to pallet height. Otherwise, even by taking the pallets out, there will not be enough space between top of stack and roof of truck to put one more bundle.
Current target diameter of NW rolls is 1000mm and 1070mm. According to data collected from suppliers information on used trucks and their filling with bundles it was discovered that average deck area utilization is approximately 67%, leaving place for improvement.
The discussion above is summarized in Figure 5.1. According to this figure it is promising to look into two options: increase in volume based VFR with trucks substitution and increase in deck area utilization with and without trucks substitution. In case of deck area utilization the problem can be simplified into a two-dimensional problem of filling a rectangle of a particular size with circles of the same diameter. This problem is known as circle packing problem and is discussed in various literature sources C.O. Lopez (2011); Kallrath (2007); E.G. Birgin (2005); M. Hifi (2004). Moreover, there is a lot of software available in the market to optimize packing of cylindrical bundles inside containers or

VFR metric	Current situation	Possible improvement if same transport is used	Possible improvement if to substitute current transport with transport with bigger dimensions
Weight	Less than 50%	Need to look at volume based VFH as trucks are filled faster than the weight limit is achieved	
Volume	61%/ 49%	Small improvement, only if to reduce pallet usage for rolls of small widths	Big improvement if to substitute smaller trucks with bigger trucks and containers. However, can effect inventory and transportation cost for one truck can be higher
Deck area	67%	Big improvement	Big improvement

Figure 5.1: Summary on VFR Situation with NWs

trucks, for example Cube IQ that was used in this thesis for some simulations.
However, this software uses heuristic algorithms and is not always applicable in case if packing is done manually. This happens because patterns that software offers are non-symmetrical, as is shown in Figure5.2. In case of trucks packing this is a critical issue, as

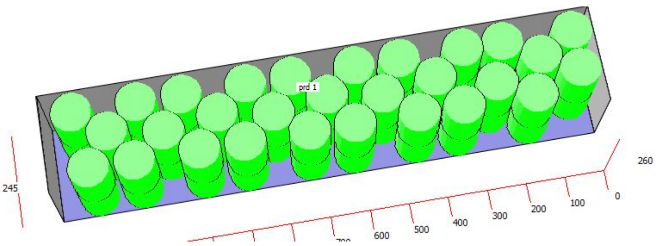

Figure 5.2: Non-symmetrical Packing of Bundles Inside a Container

truck loader will not be able to repeat a pattern precisely. Moreover, the software requires to run simulation for different roll diameters separately. In case there is a need to check, for example, five truck dimensions for diameters of 600mm to 1600mm with a step of 10mm, there is a need to run simulation around 1000 times. This is very time consuming. Therefore, in this thesis, a simple algorithm is developed and programmed in MatLab. This algorithm checks all diameters automatically, and as an output builds the graph for deck area utilization. The algorithm is takes into account only several possible symmetrical patterns of packing. It results not always in optimal solution, but allows to avoid situation of non-symmetrical packing presented in Figure 5.2, and by means of that makes it easier for the truck loader to follow the logic of packing.
In following section deck area utilization is discussed in further detail. A mathematical

model developed to calculate deck area utilization is presented. In Section 5.2 the simulation of this model and the results for different trucks and container sizes are presented, together with conclusion and suggestions. In the last section of this chapter volume utilization is presented.

5.2 Deck Area Utilization

As stated above, the problem of truck and container filling with bundles can be looked as two-dimensional problem of filling a rectangle of particular size with circles of the same diameter. In literature this problem has received a lot of attention. There are many approaches to solve the problem. For instance, search of geometrical pattern, geometrical calculus, heuristic algorithms, etc. [p.2]M. Hifi (2004).
The problem of circle filling inside container intuitively has two solutions. One of them is to fill more bundles on the deck by maximizing the deck area. Thus the solution advocates the use of bigger TUs. However, this is not always possible due to unavailability of TUs of particular size in the market, impact on warehousing and agility.The second solution is to choose the optimal diameter of rolls without changing the size of TUs.
In this thesis it is assumed that the pattern should be as symmetrical and simple as possible to make it easier for any truck loader to fill the truck. Consequently, there is no need to use heuristic algorithm to find the optimal packing pattern. Simple symmetrical geometrical model is developed and presented in Figure 5.3. The mathematical description and MatLab code is shown in Appendix A and B. To develop the model several unloading procedures were observed to form the basic understanding of what can be seen inside container or truck after it is loaded. The model takes into account several most probable

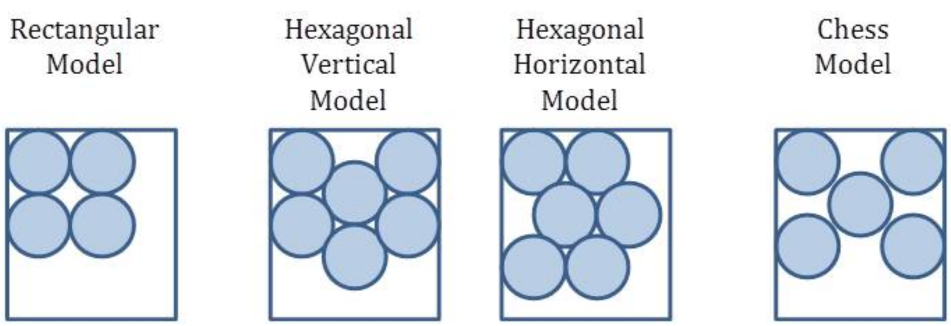

Figure 5.3: Possible Pattern Configurations for Geometrical Model of Container Packing for NWs

patterns: rectangular, hexagonal horizontal, hexagonal vertical and chess pattern. The difference between hexagonal and rectangular model from chess model is that, in chess model it is assumed that outer circles always touch container wall, while in rectangular and hexagonal model it is assumed that circles touch each other and can be located at a distance to the wall. However, hexagonal and rectangular patterns are sometimes a special case of chess model, namely when circles are touching the walls of container and each other at the same time.

5.3 Modeling and Results

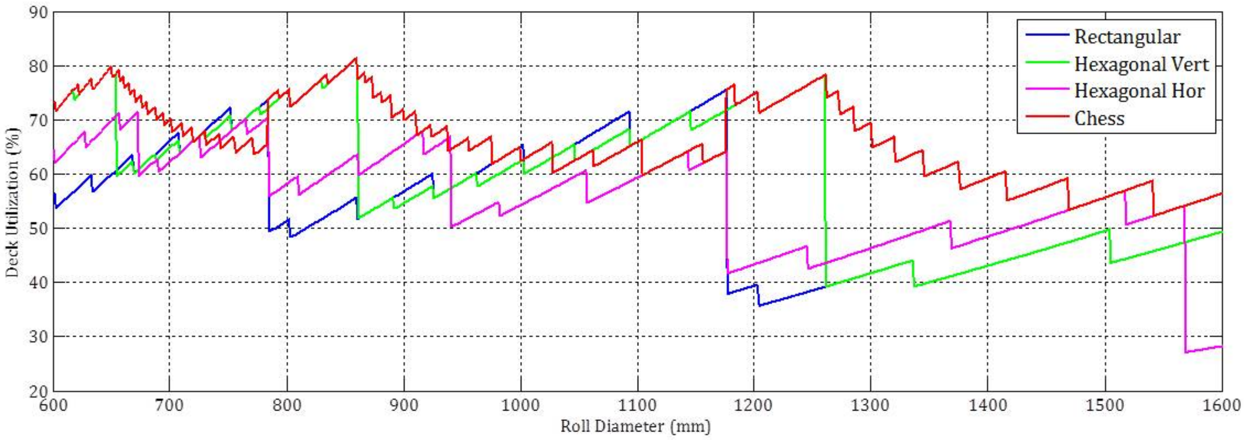

Figure 5.4: Deck Area Utilization for 40’ ISO Container

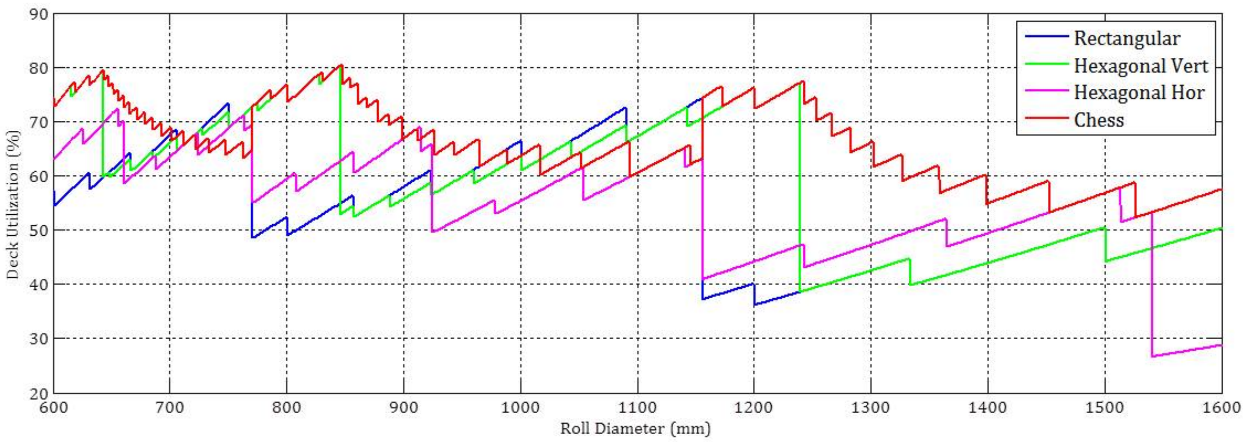

Figure 5.5: Deck Area Utilization for 40’ HC ISO Container

The geometrical model, described in Section 5.1, is simulated for most commonly used containers and trucks and the results are presented in Figures 5.4-5.7. This is done for 40’ ISO container, 40’ HC (High Cube) ISO container, Euro truck and Jumbo truck

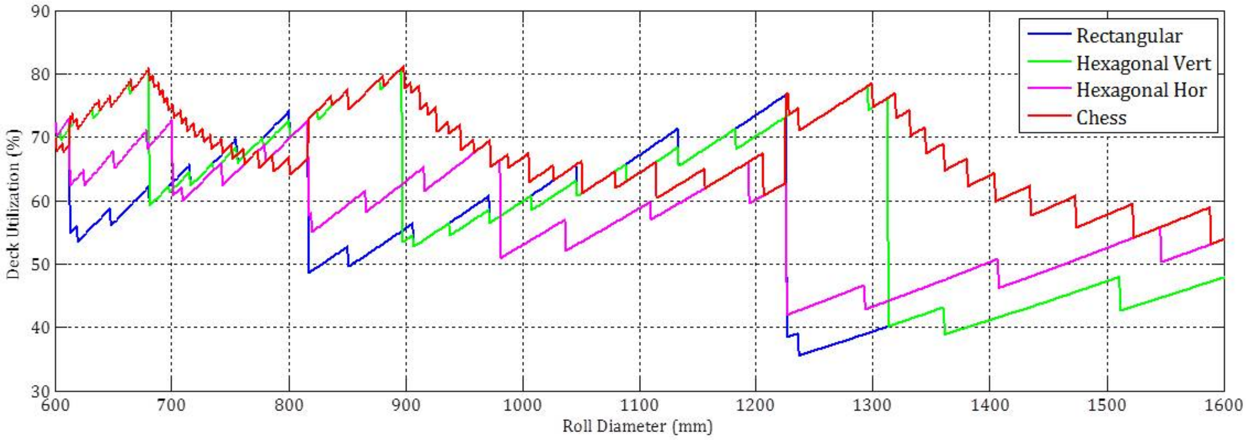

Figure 5.6: Deck Area Utilization for Euro Truck

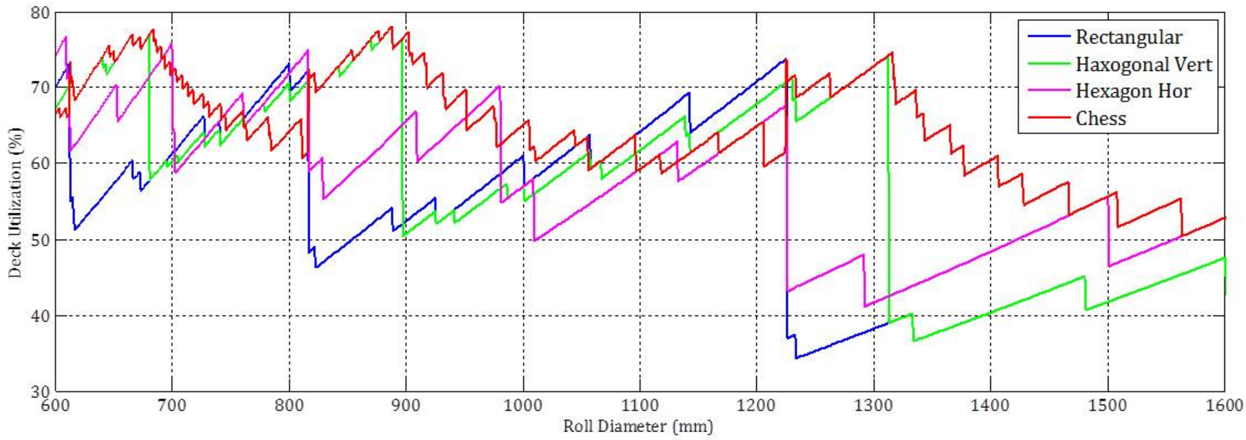

Figure 5.7: Deck Area Utilization for Jumbo Truck

whose dimensions are summarized in Table 5.1. These trucks, according to interviews with suppliers, are used for transportation of RMs in active lanes.

Table 5.1: Transport Units for NWs Active Lanes

Type of Transport Unit	Width , mm	Length, mm
40’ Container	2352	12032
40’ HC Container	2311	12000
Euro truck	2450	13600
Jumbo truck	2450	7400+8000

From the above graphs it can be concluded that for deck area utilization current diameters of 1000mm and 1070mm are not optimal for any TU (Transport Unit) used, and are around 67%. From calculations performed with the data provided by suppliers, the average deck area utilization for all NWs is 67,41%. These two values are in the same range. However, from the model results it can be seen that there are maximums of deck area utilization for certain diameters. This happens because circles touch each other and walls in a way so that less air remains in between, as is shown in the Figure 5.8. Even from an intuitive view it is obvious that bundles are more compactly packed on the right side of the figure than on the left. It can be concluded that the maximums for different TUs are not the same.

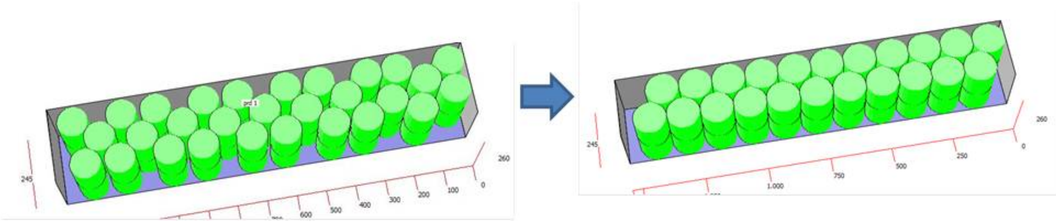

Figure 5.8: Packing Inside TUs

However, they occur near the same ranges of 650-690mm, 800-900mm, 1170-1300mm. This happens because deck area dimensions differ only slightly in width from each other. The maximums show the improvement of deck area utilization of up to 80%. Maximum for lower diameters is slightly higher, however, decrease of roll diameter will result in smaller roll life time. As roll change is done manually by operators and requires a lot of time, it is not effective to decrease roll diameter from operations point of view. The increase in roll diameter to 1200-1300mm is considered in this thesis. As highest peaks of graphs for different TUs are slightly shifted towards each other, as it is shown in Table 5.2.

Table 5.2: Maximums of Deck Area Utilization and Optimal Roll Diameter for Different Types of TUs

Type of TU	Optimal Diameter,mm	Deck VFR, %	Deck Utilization, m^2	Comments
40’ Container	1261	78,28	22,15	Chess model
40’ HC Container	1242	77,45	21,48	Chess model
Euro truck	1299	78,46	26,14	Chess model
Jumbo truck	1316	74,69	28,18	Chess model

Consequently, it is difficult to tell what is the optimal diameter for a particular truck or container, but it is not possible to estimate immediately what is the optimal diameter for the complete supply chain network. An optimal diameter is dependent on the distribution of various TUs across the entire network and the amount of material that is transported by each truck.

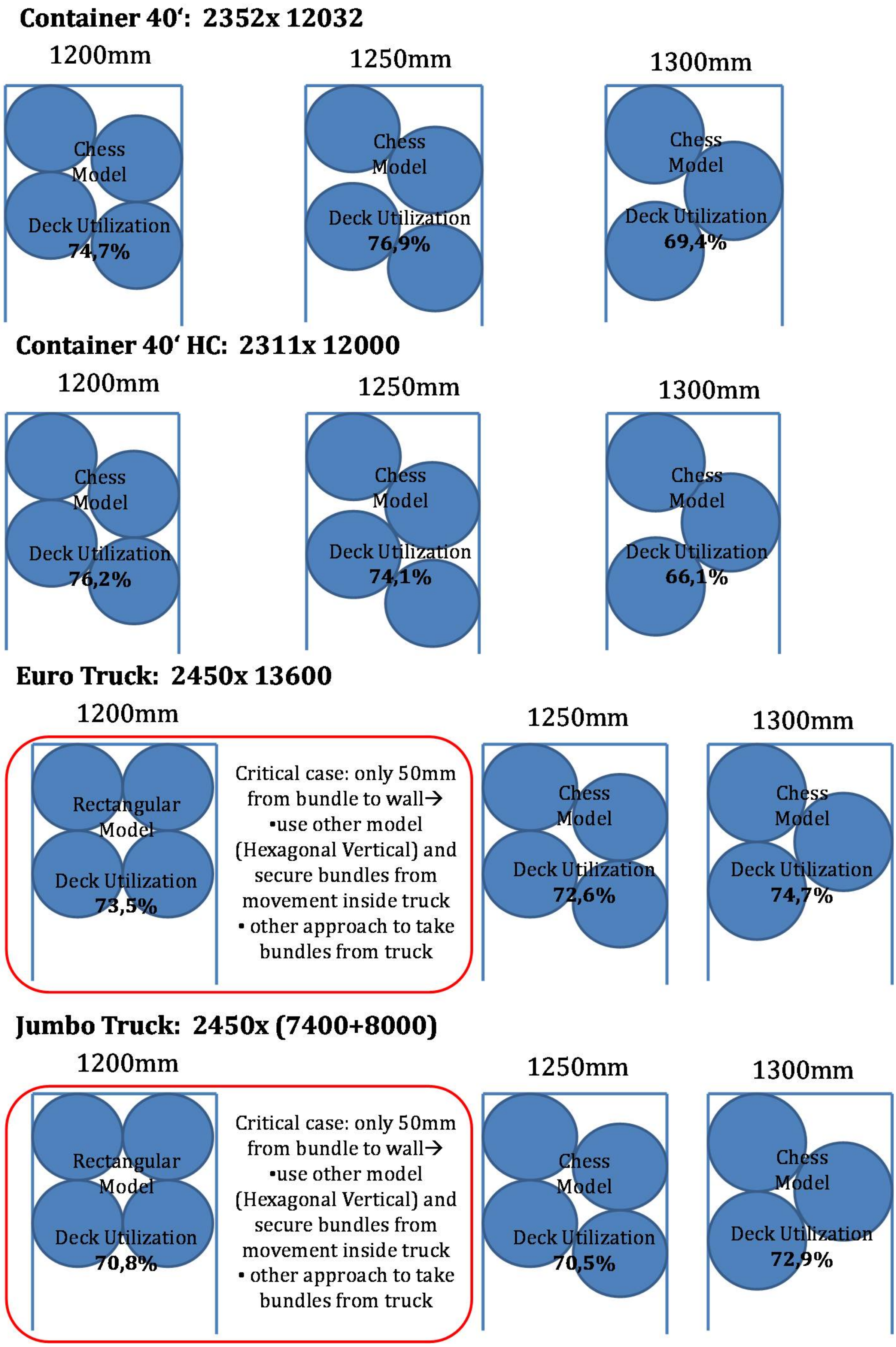

Figure 5.9: Packing Configurations for Different Roll Diameters

Moreover, as TUs types can change in time, and RM amount can deviate from forecast, it is not possible to propose a standard diameter that at the same time will be optimal from a transportation point of view. Therefore, it is decided to look into several diameters inside the range of 1200-1300mm, namely, 1200mm, 1250mm, and 1300mm. Results of transportation savings calculations, together with their possible impact on the supply chain is presented in Chapter 6. Packing patterns for different TUs for diameters of 1200mm, 1250mm, and 1300mm are presented in Figure 5.9. For Euro truck and Jumbo truck there is a difficulty in using and optimal packing pattern for diameters of 1200mm, because optimal pattern is rectangular with only 50mm left between bundle and wall of the truck. Consequently, a different approach to take bundles from the truck should be developed, or another model should be used for packing, namely, Hexagonal Vertical, as is shown in Figure 5.10. In this case bundles need to be secured from movement inside the truck.

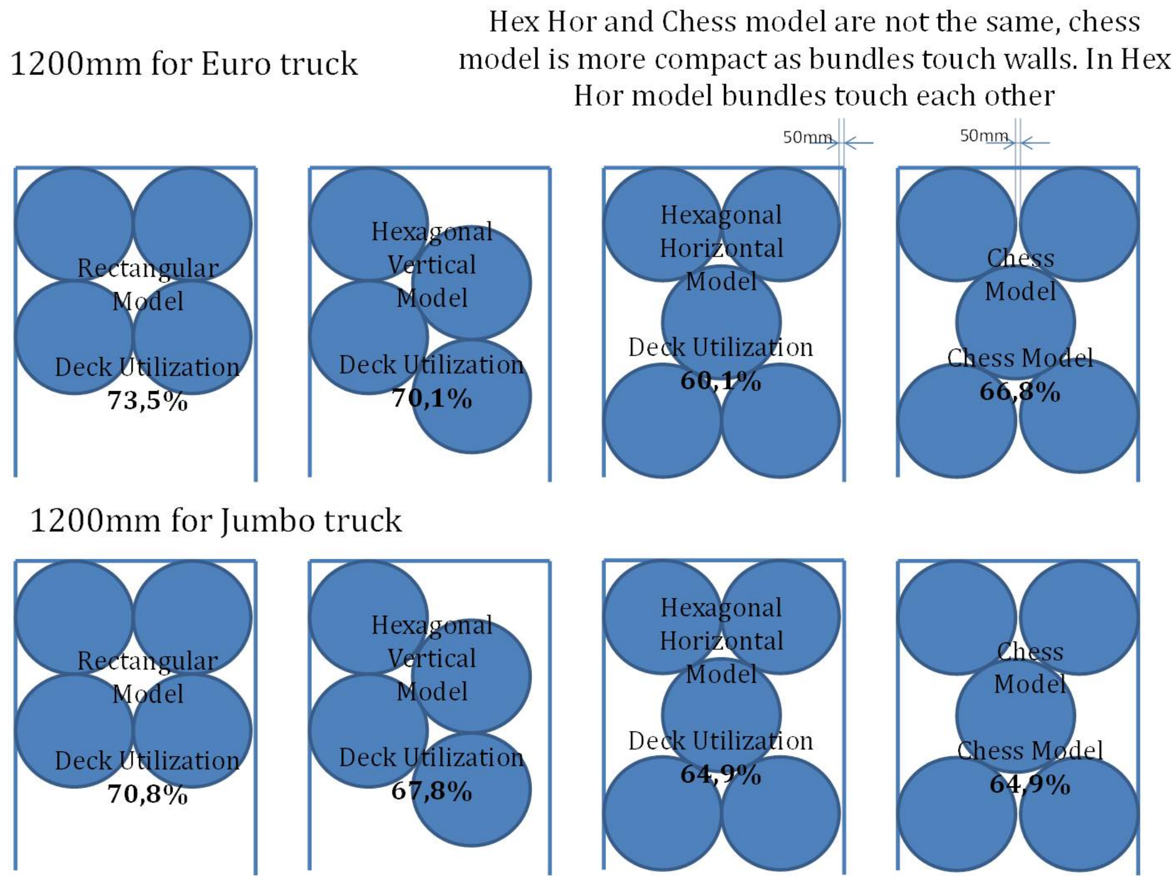

Figure 5.10: Packing Configurations for 1200mm Roll Diameters for Jumbo and Euro Trucks

5.4 Volume Utilization

The volume VFR can be seen as an extension of deck area VFR optimization problem. As was discussed above, suppliers of NWs pack bundles inside TUs using all possible height available. Consequently, there is not to much place left to optimize volume VFR assuming that TUs are not changed. However, bigger trucks or containers can be used for transportation, allowing more material inside TU. In Table 5.3 it is shown how many m^3 of bundles in average can be packed inside each of the TUs under observation.

Table 5.3: Average Transported Volume of NWs vs TU

Type of TU	Width,mm	Length, mm	Height,mm	Volume VFR, %	m^3
40’ Container	2352	12032	2385	61,41	4144,8
40’ HC Container	2311	12000	2650	61,61	4527,7
Euro truck	2450	13600	2600	61,86	5359,1
Jumbo truck	2450	7400+8000	2950	56,3	6266,4

It can be seen that even though the volume VFR for Jumbo truck is smaller than for Euro truck, more volume can be packed inside Jumbo truck. This makes it more attractive to use Jumbo trucks for transportation in case if transportation price for m^3 is growing slower than packed volume. This approach has a lot of drawbacks. First of all, the availability of bigger transport units on the market has to be checked and taken into account. Additionally, transportation price of bigger TUs can be more than transportation price for smaller trucks or containers. All this should be taken into account in calculation of the financial benefit from changing TUs.

In this thesis it is assumed that transportation units remain the same for particular lanes and all further calculations are done with this assumption.

Chapter 6

Financial Analysis

In this chapter financial analysis is presented.
The solution proposed in Section 5 influences NWs supply chain in more way than only transportation savings. It impacts the complete supply chain. Therefore, the financial analysis of changed roll diameter should be done for the entire supply chain. In Section 6.1 explanation of how implementation of the project can influence supply chain of NWs starting from supplier process and ending with production process of diapers is given.
There are several possible scenarios for the future of the project due to other parallel projects that have recently been initiated by other departments. Depending on the future of these projects, different outcomes and financial benefits for current project can follow. Consequently, Section 6.2 explains possible scenarios and provides financial calculations for each of them for WE and CEET regions.

6.1 Impact on Supply Chain

This section provides detailed explanation of how increase in NWs roll diameter influences different segments of supply chain. First, the impact on suppliers is presented, taking into account suppliers production processes and warehouse facilities. Moreover, possible transportation financial benefit from changed diameter is discussed. Since financial analysis over the complete portfolio of diameters is too broad, reasonable diameters are picked from the complete scope for further analysis. In addition, impact on P&G is shown starting from warehousing and ending with production process of diapers. A short summary of this section is presented in Figure 6.1 and is explained below.

Impact of Solution on Supplier

From supplier interviews it is discovered that suppliers can produce NWs rolls with di-

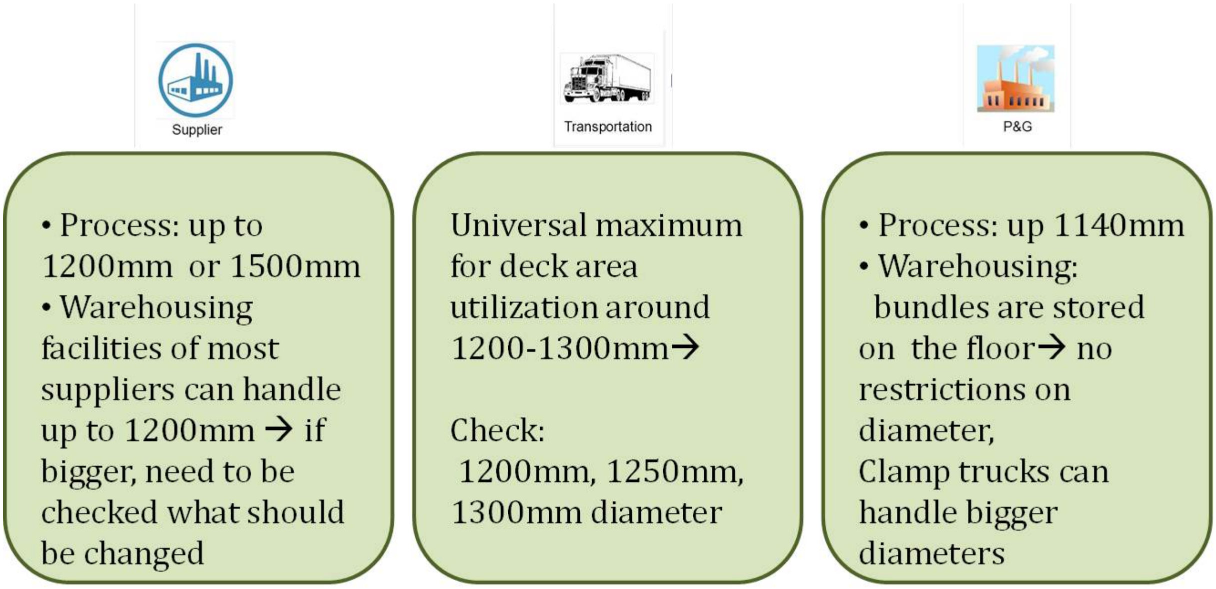

Figure 6.1: Overview of Impact of Solution on Supply Chain

ameters up to 1200mm or 1500mm dependent on the equipment they have for production process. Consequently, in the market there are manufacturers that can produce diameters in the range from 1200mm to 1300mm, where universal maximum for different TU roll diameter is located. For diameter of 1200mm there is no need to change suppliers or their equipment as all suppliers are capable of producing 1200mm rolls. However, if to increase diameter further, there is a need to restructure the supply chain by purchasing material from suppliers that can produce bigger rolls or take into account investments required for the current suppliers in order to purchase and install new equipment. In this thesis it is assumed that supplier network is reorganized in such a way that all suppliers can produce diameters up to 1300 mm without changing equipment. Therefore, investments on equipment can be neglected.

Most suppliers already produce 1200mm for other customers and their warehouse facilities allow handling and storage NWs of this diameter. In case of slightly bigger diameters it may be still feasible to use the same facilities without substitution. In this thesis it is assumed that warehouse equipment of all suppliers is applicable for up to 1300mm rolls. However, this change should be discussed and tested with all suppliers before final decision on diameter is made.

Impact on Transportation

As already mentioned any diameter from 1200mm to 1300mm leads to transportation savings. Savings are calculated using DAP (Delivered at Place) prices provided by suppliers. Logic of calculation is the following:

1. As an example, according to forecast for a certain lane A 77 TUs are required every year to transport a particular type of NW (of 1000mm diameter) from supplier to P&G location.

2. By changing the diameter of the roll to 1200mm will be required 68 TUs. Similarly in case of 1250mm - 69 TUs, and 1300mm - 67 TUs.

3. If transportation price per TU for lane A is 1000 euro, in the first case (77-68)*1000=5000 euro will be saved for Lane A and for particular material only.

4. Summarizing all savings for all lanes and all NWs types, transportation savings for WE and CEET are calculated from the forecast for next one year. Results are presented in Table 6.1

Table 6.1: Transportation Savings from Increased Diameter of NW Roll for WE and CEET

Roll Diameter, mm	Transportation Savings for WE, Euro	Transportation Savings for CEET Euro	Transportation Savings Total, Euro	Comments
1200	1,043,257	498,830	1,542,087	Optimal for CEET
1250	1,179,922	471,238	1,651,160	Optimal for WE and Total
1300	407,012	290,270	697,282	

Savings vary for different lanes as they are dependent on the amount of material that is transported and transportation price of one TU per lane. Consequently, savings for WE are bigger than savings in CEET, having almost the same amount of material transported. For CEET more material is transported in shorter lanes and less material is transported in more expensive longer lanes. This signalizes that WE supply network can be further improved not only by increasing VFR, but also by restructuring the network itself.
From Table 6.1 it can be concluded that the diameter of 1200mm is optimal from transportation saving point of view for CEET, 1250mm is optimal for WE and Total of WE and CEET. However, this is true only if all suppliers strictly follow the forecast. If amount of NWs, TU and price for some lanes will change, the optimum can be shifted to other diameter.
One diameter from 1200mm to 1300mm should be chosen for NWs and this diameter should be standard for all P&G locations and suppliers. It simplifies organization of deliveries, safety regulations, production standardization, etc. As transportation optimum

can vary, other factors should be taken into account for choosing the standard diameter, such as savings and investments of suppliers and P&G.

Impact on P&G

As stated in Figure 6.1 current production lines of P&G allow diameters of rolls up to 1140mm on handlers. This limitation comes from the mechanical structure of the equipment. In order to make it possible to place bigger rolls on handles there is a need to modify equipment, namely moving apart handlers from each other and from floor. For each piece of equipment such modification costs 12,500 euro, as discussed with engineering department. Moreover, as it is discussed in Section 4, each type of NWs is supplied to the line separately through unwinding equipment. Consequently, for five NWs types under observation five pieces of equipment are needed for each line. It results in investments for all lines in region of

$$12,500 * 5 * number\ of\ lines\ in\ region * 1.4, \tag{6.1}$$

where 12,500 is price to modify one piece of equipment, 5 is the number of unwinding equipments that need to be modified, and 1.4 is the multiplication factor in order to take into account any higher investment than assumed.
Increase in roll diameter impacts not only transportation positively, but also provides manpower savings. According to Figure 4.14 nowadays it takes in average 236.8 minutes per day per line for an operator to put BS on line. If diameter increases from 1000mm to 1200mm, amount of material in one roll increases $(1200/1000)^2 = 1.44$ times, and, consequently, time to place rolls on line decreases 1.44 times. Manpower savings in minutes per day per line to place BS on line are

$$236.8\,min - \frac{236.8\,min}{1.44} = 72.4\,min = 1.2\,hour, \tag{6.2}$$

Assuming that operator average salary for WE is 40 euros per hour it is easy to calculate manpower savings for BS in euro per day per line:

$$1.2hour\ 40\frac{euro}{hour} = 48\,euro, \tag{6.3}$$

Manpower savings are calculated for WE and CEET in hours per line per day, and in euros for all lines per year, and are presented in Table 6.2. In this calculation salary of operator in WE region is assumed to be 40 euro and in CEET 20 euro (average salary of operator is approximated as it is different for different plants).

Table 6.2: Manpower Savings for Line Loading for WE and CEET Regions

Roll Diameter, mm	Manpower Savings per Line per Day, Hour	Manpower Savings per Line per Day for WE, Euro	Manpower Savings per Line per Day for CEET, Euro
1200	5.76	230.4	115.2
1250	7.44	297.6	148.8
1300	9.84	393.6	196.8

From warehousing point of view there are no investments needed for P&G. Material is stored on the floor and change in dimensions does not impact storage. Moreover, handling equipment allows to transport rolls of 1300mm. Savings for unloading procedure are calculated using the same logic as for line loading procedure and are presented in Table 6.3.

Table 6.3: Manpower Savings for TU Unloading for WE and CEET Regions

Roll Diameter, mm	Manpower Savings per Line per Day, Hour	Manpower Savings per Line per Day for WE, Euro	Manpower Savings per Line per Day for CEET, Euro
1200	0.26	10.45	5.2
1250	0.25	9.91	4.9
1300	0.26	10.30	5.1

As a summary of this section following conclusions can be made:

1. On the negative side of financial calculations are investments on production equipment of P&G, production and warehousing equipment of suppliers (assuming that there are no investments needed for supplier equipment substitution). On the positive side are transportation savings and manpower savings from line loading and TU unloading.

2. DAP prices for different lanes are taken from supplier interviews. Approximately 10% of prices are missing. These prices are approximated to average price due to network uniformity.

3. TUs are assumed to be the same in future, without substitution to other types of TU.

4. Volume of transported material is assumed to be the same as in forecast for the next year.

6.2 Financial Analysis

According to information provided by other departments there are three possible scenarios of the project future. These scenarios are shortly listed in Figure 6.2.

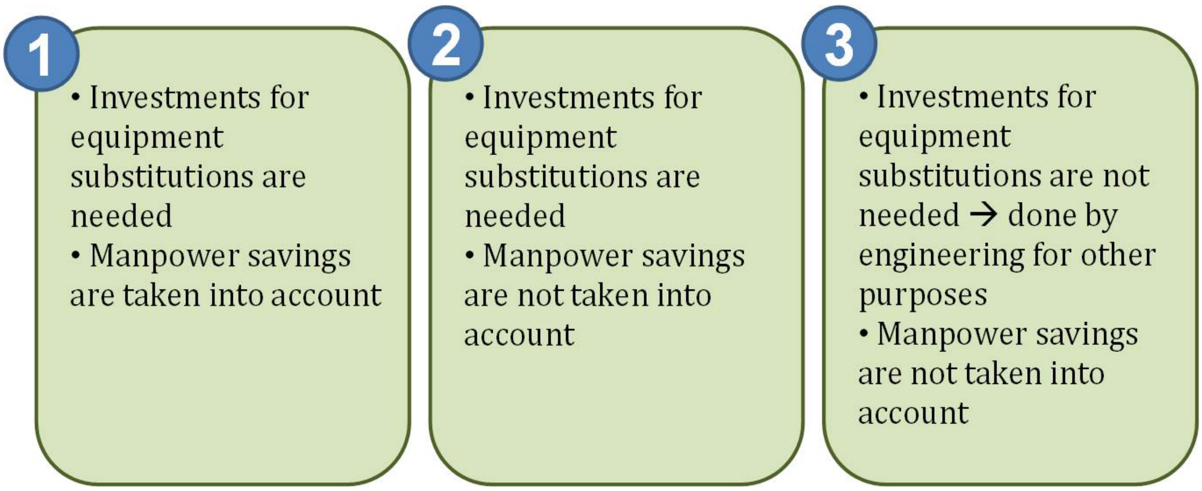

Figure 6.2: Possible Scenarios of the Project Future

The first scenario is when investments in equipment for diaper production are taken into account, and manpower savings are also included in the calculation. From the Table 6.1 it can be seen that for 1200mm diameter 5.76 hours of manpower per day are saved. Taking into account that there are three shifts every day, this means that 1.92 hours per shift are saved. This saving does no allow the removal of one of operators from the line completely. Therefore, it is necessary to redistribute the activities of operator to other tasks in order to realize the savings. Otherwise, they can not be included in the positive side of financial analysis. In first scenario it is assumed the operator is busy with other activities during saved time. For the second scenario it is assumed that operator is not involved in other activities during saved time and is waiting.
Third scenario is provided by the engineering department which is planning to substitute equipment for diaper production due to other reasons than transportation savings. This new equipment will allow to place rolls of 1300mm on the production line. Consequently, there is no need to include equipment substitution in the calculation. Moreover, manpower savings will be already included in the financial analysis of engineering project. Namely, the third scenario is looking purely in transportation savings. In this case 100Meuro of investments are assumed as project budget.

According to all stated above, financial analysis for WE and CEET is performed for all three possible scenarios. Assumptions for financial calculations are presented in Table 6.4. Numbers in this table are provided by the financial department of P&G.

Table 6.4: Assumptions for Financial Calculations

Region	Number of Lines	Interest Rate %	Tax Rate % Years	Project Life Time Euro per Hour	Operator Salary
WE	29	8.5	9	5	40
CEET	29	12.5	10	5	20

NPV (Net Present Value), IRR (Internal Rate of Return), and Payback Period calculations are shown in Tables **??**. Description of metrics is taken from (Lester, 2007, p.20-26) and presented below:

$$NPV = \sum_{i=1}^{n} \frac{B_i}{(1+r)^i}, \tag{6.4}$$

where n is project life time, r is interest rate B_i is annual net benefit in year i.
From the formula it follows that discount rate and NPV are inversely proportional. Therefore, the bigger is interest rate the lower is NPV. he point when NPV becomes zero is characterized by IRR. It can be calculated by the method of trial and error.
Payback period is the amount of time that is needed to equalize net income and original investments. It can be calculated by summing up all net incomes until summation becomes equal to initial investment. If initial investment is, for instance, 100 Meuro and net income is 50 Meuro per year, the payback period is equal to two years: $100/50 = 2$. An example of financial calculations for WE 1200mm diameter is presented below.
From Equation 6.1 it follows that investment needed to modify diaper production equipment for all 29 lines in WE region is

$$12,500 * 5 * 29 * 1.4 = 2,537,500 euro. \tag{6.5}$$

Transportation savings for the diameter 1200mm are calculated in Table ref{transpsavings for all lines in WE for one year, and are 1,043,25 euro. Manpower savings include unloading of TUs and line loading. In Table 6.2 it is shown that manpower savings are 230.4 euro per line per day. Multiplying this value with 365 days and 29 lines, manpower savings per line loading for all WE lines per year are 230,4*365*29= 2.438,8 $Meuro$. The same logic is applicable to TU unloading. From Table 6.3 it can be seen that savings for one day are

10.45 euro. Consequently, savings for all lines of WE per year are 10.45*365*29 = 110.6 $Meuro$.

Total savings for one year, including total manpower savings and transportation savings, in this case are:

$$2,438.8 + 110.6 + 1,043.3 = 3,592.7 Meuro. \tag{6.6}$$

This value is pure savings that does not include taxes. As tax rate for WE is 9% total savings after taxes are 3,592.7(1-0.09)=3,269.3 Meuro.

In calculations of cash flow not only total net savings should be included, but also depreciation tax relief for equipment. Details about depreciation calculations can be found in C.Gowthorpe (2011). In Table 6.5 depreciation calculations are shown.

Table 6.5: Depreciation Calculations for 1200mm Roll Diameter for WE(First Scenario)

Metric	Year1	Year2	Year3	Year4	Year5	Total
Depreciation Convension, %	20	32	19.2	11.5	11.5	
Capital Spending, euro	(2,537,500)					
Tax Depreciation Expense, euro	507,500	812,000	487,200	292,320	292,320	2,391,340
Residual Undepreciated Balance, euro					146,160	
Total Tax Depreciation Expense, euro	507,500	812,000	487,200	292,320	438,480	2,537,500
Total Tax Relief, euro	45,675	73,080	43,848	26,309	39,463	228,375

Total cash flow per year is depreciation tax relief plus net revenue minus investments. To calculate NPV, cash flow of every year should be discounted with assumed interest rate for WE of 8.5%, and added as shown in Equation 6.4. The summary of this calculation is presented in Table 6.6.

Table 6.6: NPV for 1200mm Roll Diameter for WE(First Scenario)

Metric	Year1	Year2	Year3	Year4	Year5	Total
Capital Spending, euro	(2,537,500)					
Net Revenue, euro	3,269,321	3,269,321	3,269,321	3,269,321	3,269,321	
Total Tax Relief, euro	45,675	73,080	43,848	26,309	39,463	
Total Cash Flow, euro	777,496	3,342,401	3,313,169	3,295,630	3,308,784	14,037,479
Discounted Cash Flow, euro	644,998	2,957,426	2,701,900	2,477,047	2,292,105	10,967,832

The same logic is applied for calculations for other diameters, future project scenarios and other regions, namely CEET. Results are summarized in Tables 6.7 and 6.8.
From Tables 6.7 and 6.8 it can be concluded that for the first scenario of project future, when manpower is assumed to be used for other tasks, for both WE and CEET regions, higher NPV results for 1300mm rolls. However, further negotiations and tests on supplier side are needed in order to understand if warehouse and production equipment of suppliers is able to handle and produce this size of rolls. 1200mm diameter already provides savings that are more than 10 million euro and in this case there is no need in investments on supplier side.
For the second scenario positive NPV is only for 1200mm and 1250mm for WE region. For CEET all diameters provide negative NPV. This means that without manpower redistribution investments in equipment do not make sense considering only pure transportation savings.
Neglecting investments in equipment and only looking into transportation savings, NPV is positive in all cases as investments are very low compare to the profit. Diameter of 1200mm is optimum for current supply network for CEET, and 1250mm is optimum for WE. However, as stated above, diameter should be standard across all P&G plants. 1200mm option is preferable in this stage of discussion due to confident statement of

suppliers that they can handle rolls of 1200mm.

Table 6.7: Summary of Financial Analysis for WE

Diameter mm	Investments Euro	Transportation Savings per Year, Euro	Total Savings per Year, Euro	NPV Euro	IRR %	Payback Period Year
Scenario with equipment investments and redistributed manpower						
1200	(2,537,500)	1,043,257	3,592,660	10,967,832	128.77	1.27
1250	(2,537,500)	1,179,922	4,434,940	14,113,983	159.70	1.12
1300	(2,537,500)	407,012	4,682,333	15,038,065	168.73	1.09
Scenario with equipment investments and non redistributed manpower						
1200	(2,537,500)	1,043,257	1,043,257	1,445,095	27.8	3.02
1250	(2,537,500)	1,179,922	1,179,922	1,955,577	34.0	2.74
1300	(2,537,500)	407,012	407,012	-931,458	-6.3	¿5.5
Scenario with only transportation savings						
1200	(100,000)	1,043,257	1,043,257	3,800,237	951.25	0.61
1250	(100,000)	1,179,922	1,179,922	4,310,719	1075.61	0.59
1300	(100,000)	407,012	407,012	1,423,684	372.19	1.68

Table 6.8: Summary of Financial Analysis for CEET

Diameter mm	Investments Euro	Transportation Savings per Year, Euro	Total Savings per Year, Euro	NPV Euro	IRR %	Payback Period Year
Scenario with equipment investments and redistributed manpower						
1200	(2,537,500)	498,830	1,773,532	3,533,984	58.61	2.03
1250	(2,537,500)	471,238	2,098,747	4,639,358	71.48	1.80
1300	(2,537,500)	290,270	2,427,930	5,758,217	84.17	1.63
Scenario with equipment investments and non redistributed manpower						
1200	(2,537,500)	498,830	498,830	-798,596	-0.5	¿5.5
1250	(2,537,500)	471,238	471,238	-892,379	-2.2	¿5.5
1300	(2,537,500)	290,270	290,270	-1,507,471	-14.5	¿5.5
Scenario with only transportation savings						
1200	(100,000)	498,830	498,830	1,597,185	451.03	0.72
1250	(100,000)	471,238	471,238	1,503,403	426.19	0.73
1300	(100,000)	290,270	290,270	888,310	263.05	0.88

6.3 Financial Summary

Financial analysis has been done for three diameters in 1200mm-1300mm range: 1200mm, 1250mm, and 1300mm. In financial analysis, investments required by suppliers and P&G are evaluated.
Both, investments in equipment modifications and manpower savings of P&G, has been included in the analysis.
Additionally, it is assumed that all suppliers can produce and handle up to 1300mm rolls diameter. Manpower savings on supplier side has not been included as each supplier has to make calculation of profitability from this project. This can be done by performing tests and looking at the amount of manpower saved. However, assuming that no investments are needed on supplier side, there will no be negative impact on financial calculations and total NPV will only grow due to additional savings of manpower on supplier side.
As the result of financial calculations following can be concluded:

1. Preferable diameters for different regions can vary. However, preferable option on current stage of the project is 1200 mm as it is confirmed by all suppliers that no investments are needed from there side.

2. Line operator effort reduction is a key component of savings. Therefore, redistribution of manpower to other activities is necessary to realize for the savings.

3. Pure transportation savings in CEET in 5 years do not cover investments on equipment for any diameter.

4. Pure transportation savings in WE cover investments on equipment for 1200mm and 1250mm diameters.

5. For a new equipment it is recommended to design splicers that allow 1200-1300mm rolls due to transportation cost reduction.

Chapter 7

Conclusions

7.1 Summary

In this thesis VFRs for one of the raw materials used in diaper production has been evaluated.
The diaper production process has been studied. It has been discovered that materials transported in biggest volumes are NWs. Moreover, they are packed in cylindrical bundles. The same packing pattern is also used for majority of other RMs. Therefore, NWs have been chosen for further investigation. Also, the same logic, used for the analysis of nonwovens, can be reapplied for other RMs packed in bundles.
Current supply chain for NW materials has been studied and complete supply chain, starting with supplier production process and ending with production process of diapers, has been analyzed. This analysis is followed by current VFR investigation of NWs. It is discovered that NWs are light materials and volume of trucks is filled faster than allowed maximum weight. Moreover, since suppliers utilize the height of TUs to the maximum, it was decided to look into deck area based VFR. Thus, the problem of vehicle filling with bundles was simplified into two-dimensional problem of filling rectangle with circles of equal diameters.
In Section 5 the solution for VRF improvement is proposed using a simplified symmetrical model created in MatLab. It has been discovered that increase of roll diameter to 1200mm-1300mm changes current 67% VFR to approximately 78%.
Financial analysis has been done for three diameters from 1200mm-1300mm range, namely 1200mm, 1250mm, and 1300mm. In financial analysis such aspects as investments at supplier and P&G have been evaluated. It is assumed that all suppliers can produce and handle rolls up to 1300mm in diameter. However, this should be further tested by the suppliers. Moreover, investments in equipment modifications and manpower savings of

P&G has been included in analysis. It was calculated that line operator effort reduction is a key component of savings (2,439 $Meuro$ from 3,593 $Meuro$ of total savings per year), and redistribution of manpower to other activities is critical to realize the savings and justify investments of 2,5 millions euro needed for equipment.
Manpower savings on supplier side has been excluded from analysis. The addition of this calculation in future will result in further increase of NPV for 1200mm. For bigger diameters direction in which NPV will shift is dependent on investments in process and warehousing equipment of suppliers.
In current stage of the project 1200mm rolls are considered to be the most attractive due to low risks of investments on supplier side and attractive NPV of 10,968 $Meuro$ for WE and 3,534 $Meuro$ for CEET (for 5 years of project life and scenario of project future for which it is assumed that manpower is redistributed and the savings are realized). However, for a holistic analysis, all required investments for different roll diameter options should be taken into account. The summary of possible improvements and suggestions for further investigations are presented in the next section.

7.2 Next Steps

Suggestions for further research and testing on this thesis are presented below:

1. Impact of increased roll diameter on supplier for diameters bigger than 1200mm should be further investigated. Investments in suppliers' warehousing and process equipment should be added to the financial analysis. Tests on manpower savings in line loading, unloading at supplier locations should be performed, together with tests on TU loading. Results of these tests should be included in the financial analysis as well.

2. Saved manpower should be redistributed carefully for other tasks as it a key component of savings.

3. Loading and unloading tests should be performed due to substitution of TU packing patterns. Moreover, transportation possibility of this patterns should be evaluated as, during transportation, bundles can move inside TUs and material can be damaged.

4. Further financial analysis for other regions apart from WE and CEET is required. Due to standardization of diameter there is a need to look into global savings.

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Appendix A

Mathematical Model for Deck Area Calculation

In this appendix simplified symmetrical mathematical model, shortly described in Section 5.1, is presented. The model consists of four separate pattern configurations, shown in Figure 5.3. From these four patterns, the optimal pattern giving the maximum deck area utilization for particular roll diameter should be chosen. However, some exception cases do not allow to chose the optimal diameter due to unloading constraints. For example, in cases when rectangular model is a special case of chess model, all rolls touch each other and walls at the same time. Moreover, as centers of rolls lay on the same line there is no possibility to place clamp of unloading truck so that it does not damage the roll. In this case other pattern should be chosen for loading. This case is presented in Figure 4.9.

A.1 Rectangular Model

Geometry of rectangular pattern is presented in Figure A.1. According to this figure it can be concluded that number of bundles in the direction along the width of TU is:

$$m_{rect} = floor(\frac{w}{d}), \tag{A.1}$$

where w is the width of TU in mm, d is the roll diameter in mm, and $floor()$ is the function that rounds a number down to integer.

Additionally, number of bundles in the direction along

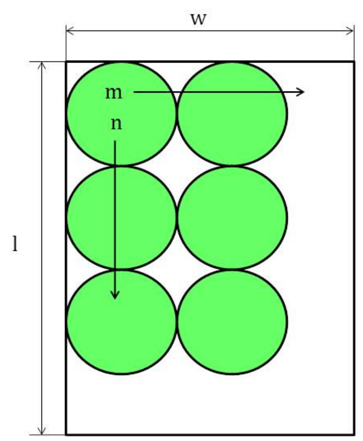

Figure A.1: Geometry of Rectangular Pattern length of TU is:

$$n_{rect} = floor(\frac{l}{d}), \tag{A.2}$$

Consequently, total number of rolls in deck of TU is:

$$number_{rect} = m_{rect} * n_{rect}, \tag{A.3}$$

where m_{rect} and n_{rect} are number of bundles in the direction along the width and the length of TU.
The total utilized deck area, if to take into account internal core, in this case can be calculated with formula:

$$deck\_bundle_{rect} = number_{rect} * bundle\_area - number_{rect} * inter\_core, \tag{A.4}$$

where $bundle\_area$ is deck area of one bundle and $inter\_core$ is deck area of one core.
The deck area of core and roll can be calculated with formula of circle area:

$$circle\_area = \pi r^2, \tag{A.5}$$

where r is radius of a circle.

A.2 Hexagonal Vertical Model

Geometry of hexagonal vertical pattern is presented in Figure A.2.

According to this figure it can be concluded that number of bundles in the direction along the width of TU is:

$$\begin{matrix} m\_odd_{hexag\_ver} = floor(\frac{w-d}{\sqrt{3}d}) + 1, & (1) \\ m\_even_{hexag\_ver} = floor(\frac{w-d-0.5\sqrt{3}d}{\sqrt{3}d}) + 1, & (2) \end{matrix}, \tag{A.6}$$

where w is the width of TU in mm, d is roll diameter in mm, $m\_odd_{hexag\_ver}$ is number of bundles in odd positions, $m\_even_{hexag\_ver}$ number of bundles in even positions.
Additionally, number of bundles in direction along length of TU is:

$$\begin{matrix} n\_odd_{hexag\_ver} = floor(\frac{l-d}{d}) + 1, & (1) \\ n\_even_{hexag\_ver} = floor(\frac{l-1.5d}{d}) + 1, & (2) \end{matrix}, \tag{A.7}$$

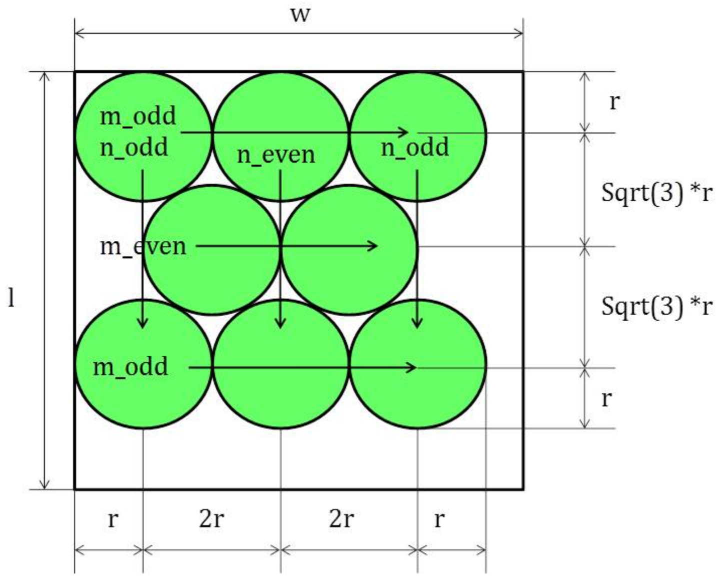

Figure A.2: Geometry of Hexagonal Vertical Pattern

where l is the length of TU in mm, d is roll diameter in mm, $n\_odd_{hexag\_ver}$ is the number of bundles in odd positions, $n\_even_{hexag\_ver}$ is the number of bundles in even positions. Consequently, total number of rolls on deck of TU is:

$$number_{hexag\_ver} = m\_odd_{hexag\_ver} * n\_odd_{hexag\_ver} + m\_even_{hexag\_ver} * n\_even_{hexag\_ver}, \quad (A.8)$$

For calculation of utilized deck area Formula A.4 can be used.

A.3 Hexagonal Horizontal Model

Geometry of hexagonal vertical pattern is presented in Figure A.3.

According to this figure it can be concluded that number of bundles in direction along the width of TU is:

$$\begin{aligned} m\_odd_{hexag\_hor} &= floor(\tfrac{w-d}{d}) + 1, && (1) \\ m\_even_{hexag\_hor} &= floor(\tfrac{w-1.5d}{d}) + 1, && (2) \end{aligned}, \quad (A.9)$$

where w is the width of TU in mm, d is roll diameter in mm, $m\_odd_{hexag\_hor}$ is number of bundles in odd positions, $m\_even_{hexag\_hor}$ number of bundles in even positions. Additionally, number of bundles in direction along length of TU is:

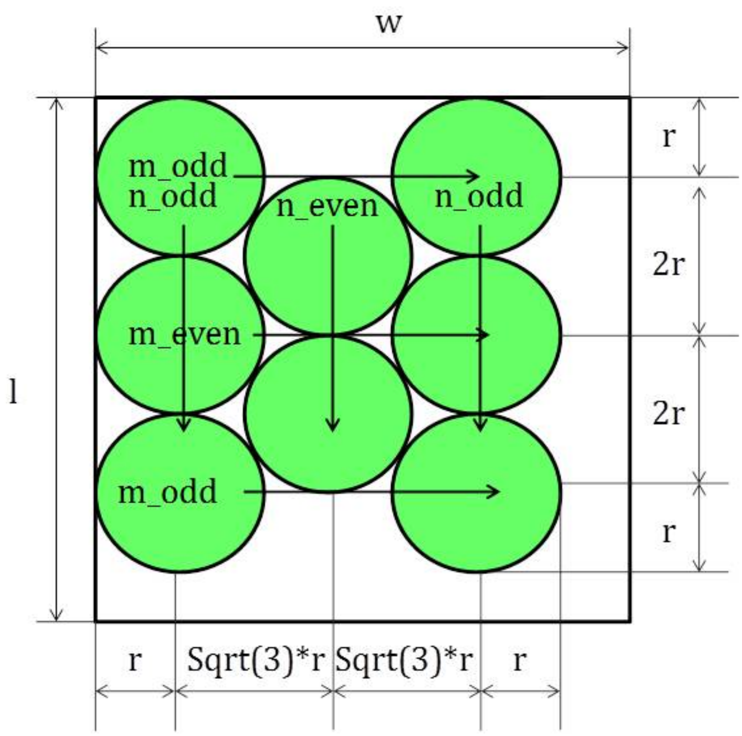

Figure A.3: Geometry of Hexagonal Horizontal Pattern

$$\begin{array}{ll} n\_odd_{hexag\_hor} = floor(\frac{l-d}{\sqrt{3}d}) + 1, & (1) \\ n\_even_{hexag\_hor} = floor(\frac{l-d-0.5\sqrt{3}d}{\sqrt{3}d}) + 1, & (2) \end{array}, \tag{A.10}$$

where l is the length of TU in mm, d is roll diameter in mm, $n\_odd_{hexag\_hor}$ is the number of bundles in odd positions, $n\_even_{hexag\_hor}$ is the number of bundles in even positions. Total number of rolls in deck of TU and the utilized deck area can be calculated using Equations A.4 and A.8.

A.4 Chess Model

Chess model is different from those presented above in the sense that outer bundles always touch the walls of TUs. It creates patterns that have no distance to walls, however bundles can have more air between each other. The geometrical model of chess pattern depends on the situation as it can be seen from Figure A.4.
From this figure it can be concluded that there are four cases of chess model that have different formulas of implementation. To separate these four cases from each other there is a need to introduce two new variables. These variables decribe the distances between circles centers in vertical and horizontal directions and can be calculated as:

$$\begin{cases} ab = \frac{w-d}{floor(\frac{w}{d})}, & (1) \\ ac = \sqrt{d^2 - ab^2}, & (2) \end{cases}, \tag{A.11}$$

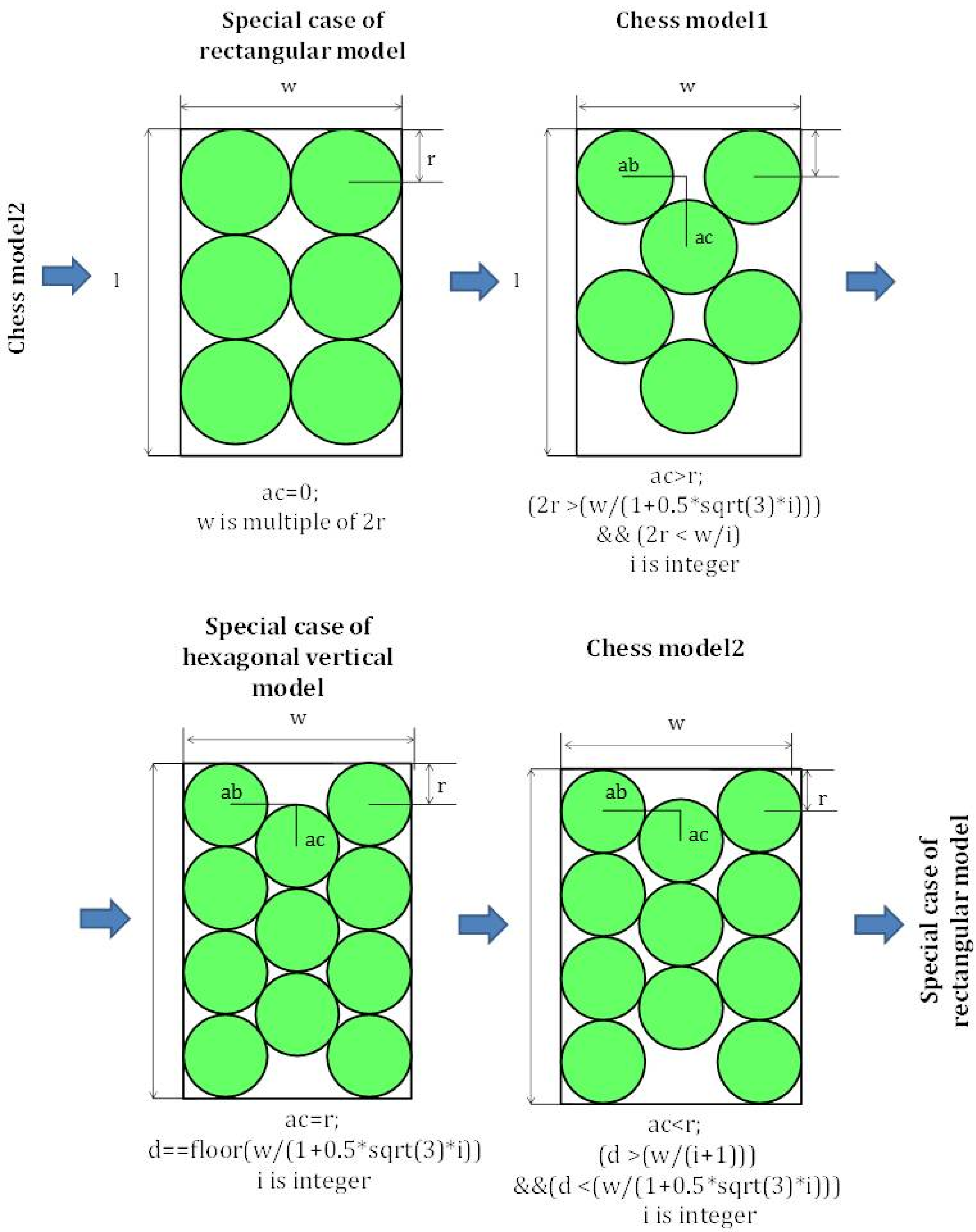

Figure A.4: Four Cases of Chess Model

All four cases together form chess model and smoothly flow into each other as relation between roll diameter and TU width changes, as is shown in the Figure A.4.
First case is the case when width of TU is a multiple of bundle diameter. This case can be viewed as a special case of rectangular model when rolls are touching also walls of truck or container. Consequently, same formulas are applicable to calculate number of rolls in deck and deck area utilization as in Section A.1.
Second case is the case when ac is bigger than radius of the bundle. For this case following formulas can be derived.
Number of bundles in direction along the width of TU is:

$$m_{m1} = ceil(\frac{w}{d}), \tag{A.12}$$

where w is the width of TU in mm and d is the roll diameter in mm.
Number of bundles in direction along length of TU is:

$$\begin{aligned} n\_odd_{m1} &= floor(\tfrac{l-d-ac}{2ac}) + 1, && (1) \\ n\_even_{m1} &= floor(\tfrac{l-d}{2ac}) + 1, && (2) \end{aligned}, \tag{A.13}$$

where l is the length of TU in mm, d is the roll diameter in mm, n_odd_{m1} is the number of bundles in odd positions, n_even_{m1} is the number of bundles in even positions.
Consequently, total number of rolls in deck of TU is:

$$number_{m1} = ceil(\frac{m_{m1}}{2}) * n\_odd_{m1} + floor(\frac{m_{m1}}{2}) * n\_even_{m1}. \tag{A.14}$$

.

Third case is the special case of hexagonal vertical model when rolls touch also walls of TUs. Therefore, formulas in Section A.2 are applicable.
Case number four is when ac is smaller than the radius of the bundle. For this case following formulas can be derived.
Number of bundles in the direction along the width of TU is:

$$m_{m2} = ceil(\frac{w}{d}), \tag{A.15}$$

where w is the width of TU in mm and d is the roll diameter in mm.
Number of bundles in the direction along length of TU is:

$$\begin{aligned} n\_odd_{m2} &= floor(\tfrac{l-ac}{d}), && (1) \\ n\_even_{m2} &= floor(\tfrac{l}{d}), && (2) \end{aligned}, \tag{A.16}$$

where l is the length of TU in mm, d is roll diameter in mm, n_odd_{m2} is the number of bundles in odd positions, n_even_{m2} is the number of bundles in even positions.
Total number of rolls in deck of TU can be calculated with the same formula as for model1, namely Formula A.14.

Appendix B

Source Code of Simulation Model

The MatLab code of the model developed in A ispresented below.

```
%--------------------------INPUT DATA------------------------------------
l=13600; % length of TU
w=2450;  % width of TU

deck_area = l*w; %deck area of TU
min_d = 600;     %minimum diameter under observation
max_d = 1800;    %maximum diameter under observation
core= 152,4;      %core diameter

%-----------------------------SETUP---------------------------------------
size=max_d -min_d +1;
m_fill = zeros(1, size);
n_fill = zeros(1, size);
lost_min = zeros(1, size);

for d = min_d:max_d

    %----------------------------PARAMETERS------------------------------

    bunde_area(d) = pi*(d/2)^2; % deck area of bundle
    inter_core= pi*(152/2)^2; %deck area of internal core
    ab(d)=(w-d)/(floor(w/d));
    ac(d)=sqrt(d^2-ab(d)^2);

    %------------------------RECTANGULAR MODEL----------------------------

    % number of bundles along the width of TU
    m_rect(d) = floor(w/d);
```

```
% number of bundles along the length of TU
n_rect(d) = floor(l/d);

% total number of bundles in deck
number_rect(d)=m_rect(d)*n_rect(d);

% total utilized deck area
deck_bundle_rect(d) = number_rect(d)*bunde_area(d)
                      -number_rect(d)*inter_core;

%deck area utilization for rectangular model
lost_rect(d) = 100*deck_bundle_rect(d)/deck_area;

%------------------------HEXAGONAL MODEL VERTICAL----------------------

% number of bundles along the width of TU on odd positions
m_odd_hexag_ver(d) = floor((w-d)/(sqrt(3)*d))+1;

% number of bundles along the width of TU on enen positions
m_even_hexag_ver(d) = floor((w-d-0.5*sqrt(3)*d)/(sqrt(3)*d))+1;

% number of bundles along the length of TU on odd positions
n_odd_hexag_ver(d) = floor((l-d)/d)+1;

% number of bundles along the length of TU on even positions
n_even_hexag_ver(d) = floor((l-1.5*d)/d)+1;

% total number of bundles in deck
number_hexag_ver(d) = m_hexag_border(d)* n_hexag_border(d)
                 + m_hexag_middle(d)* n_hexag_middle(d);

% total utilized deck area
deck_bundle_hexag_ver(d) = number_hexag(d)*bunde_area(d)
                      -number_hexag(d)*inter_core;

%deck area utilization for hexagonal vertical model
lost_hexag_ver(d) = 100*deck_bundle_hexag(d)/deck_area ;

%------------------------HEXAGONAL MODEL hORIZONTAL--------------------

% number of bundles along the width of TU on odd positions
m_odd_hexag_hor(d) = floor((w-d)/d)+1;

% number of bundles along the width of TU on enen positions
m_even_hexag_hor(d)) =floor((w-1.5*d)/d)+1;
```

```
% number of bundles along the length of TU on odd positions
n_odd_hexag_hor(d)=floor((l-d)/(sqrt(3)*d))+1;

% number of bundles along the length of TU on even positions
n_even_hexag_hor(d) = floor((l-d-0.5*sqrt(3)*d)/(sqrt(3)*d))+1;

% total number of bundles in deck
number_hexag_hor(d) = m_hexag_hor_border(d)* n_hexag_hor_border(d)
                      + m_hexag_hor_middle(d)* n_hexag_hor_middle(d);

% total utilized deck area
deck_bundle_hexag_hor(d) = number_hexag_hor(d)*bunde_area(d)
                           -number_hexag_hor(d)*inter_core;

%deck area utilization for hexagonal horizontal model
lost_hexag_hor(d) = 100*deck_bundle_hexag_hor(d)/deck_area ;

%------------------------------CHESS MODEL----------------------------

% Model 1:
m_m1(d)=ceil(w/d);
n_even_m1(d)=floor((l-d-ac(d))/(2*ac(d)))+1;
n_odd_m1(d)=floor((l-d)/(2*ac(d)))+1;
number_m1(d) = ceil(m_m1(d)/2)*n_m1_border(d) + floor(m_m1(d)/2)* n_m1_middle(d);
deck_bundle_m1(d) = number_m1(d)*bunde_area(d)-number_m1(d)*inter_core;
lost_m1(d) = 100*deck_bundle_m1(d)/deck_area;

% Model 2:
m_m2(d)=ceil(w/d);
n_even_m2(d)=floor((l-ac(d))/d);
n_odd_m2(d)=floor(l/d);
number_m2(d) = ceil(m_m2(d)/2)*n_m2_border(d) + floor(m_m2(d)/2)* n_m2_middle(d);
deck_bundle_m2(d) = number_m2(d)*bunde_area(d)-number_m2(d)*inter_core;
lost_m2(d) = 100*deck_bundle_m2(d)/deck_area;


% Assign special cases of chess model:
for i=1:4

    %if CASE1, model 1
    if ((d > (w/(1+0.5*sqrt(3)*i))) && (d < w/i))
        number_fill(d) = number_m1(d) ;
        deck_bundle_fill(d) = deck_bundle_m1(d);
        lost_fill(d) =  lost_m1(d);
```

```
        %if CASE2, model 2
        elseif ((d >(w/(i+1))) &&(d <(w/(1+0.5*sqrt(3)*i))))
            number_fill(d) = number_m2(d);
            deck_bundle_fill(d) = deck_bundle_m2(d);
            lost_fill(d) =  lost_m2(d);

        %if CASE3, rectangular model
        elseif (d==w/i)
            number_fill(d) = number_rect(d);
            deck_bundle_fill(d) = deck_bundle_rect(d);
            lost_fill(d) =  lost_rect(d);

        %if CASE4, haxagonal model
        elseif (d==floor(w/(1+0.5*sqrt(3)*i)))
            number_fill(d) = number_hexag_ver(d);
            deck_bundle_fill(d) = deck_bundle_hexag_ver(d);
            lost_fill(d) =  lost_hexag_ver(d);

        end
    end
```

Appendix C

Interview With Suppliers

A: Possibe transportation modes used by supplier

Transportation mode (pick from list)	Trailer size (internal dimensions in mm (width-length-height) mm)

Transportation mode details

Supplier	P&G Plant	Transportation mode	Incoterms	Lane manager	Trailer size	Weight limitation for container/truck	Total price per container/truck	Transportation price per container/truck	Pallets	Dimensions of pallets (width-length-height)	Material of pallets
Pick from list	Pick from list	Pick from list			Pick from list (specified in table A)	kg	Euro	Euro	Pick from list	mm	Pick from list

Packaging details: part 1

Parameter	Supplier	Material Type1	Material Type2	Grams/sqm	Width of roll	Diameter or ro	Weight of roll	Packing Specs					
								Without Pallet					
								Length of material in single roll	Hight of one bundle	Gross weight of one bundle	Number of bundles in one stack	Trailer size	Average number of stacks in one truck
Comments	Pick from list		Pick from list	Pick from list	Pick from list	mm	kg	mm	mm	mm		Pick from list (specified in table A)	Dependent of trailer size

Packaging details: part 1

With Pallet							
Type of pallet used or NA	Material of pallet	Number of bundles on one pallet	Hight of pallet (with bundles)	Gross weight of one pallet (with bundle)	Number of pallets in one stack	Trailer size	Average number of stacks in one truck
Pick from list	Pick from list		mm	mm		From list (specified in table A)	Dependent of trailer size