UNIVERSITE CATHOLIQUE DE LOUVAIN
LOUVAIN SCHOOL OF MANAGEMENT

Supply Chain Optimization of the Lhoist Network in Malaysia

Confidential

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UNIVERSITE CATHOLIQUE DE LOUVAIN

Abstract

Louvain School of Management
Department of Operations and Information Systems

Master in Business Engineering

Supply Chain Optimization of the Lhoist Network in Malaysia

by Kevin Puylaert

The aim of this thesis is to optimize the supply chain of the Lhoist Network in Malaysia, and to make a recommendation about how Lhoist Malaysia should evolve their supply chain. In the first part a short situation is presented. It shows the many changes Lhoist had in Malaysia over the last months. The thesis then identifies how such optimizations are usually realized. In the appendix, one of the methods is applied on the business case in Lhoist Malaysia. In conclusion, the thesis argues that Lhoist should adapt its supply chain in Malaysia and recommends an investment in a larger facility.

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The constant mix of day to day work and project building in an open team has been a very rewarding experience.

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Chapter 1

Introduction

1.1 Description of the content

In the first chapter of this thesis we will first sketch a general background of Lhoist and the operations of Lhoist in Malaysia. We will then expand the research question that we will answer in the course of this thesis.

In the second chapter we will describe the state of the production distribution literature. We will describe both the method and tools that were used to solve the problem and the methods that theoretically would be used to solve the question.

In the appendix we will describe in detail the application of the problem. The problem will be analyzed from a sales, a production and a distribution point of view. The centre of attention will be on the strategic implications.

Finally in the last chapter we will discuss the theoretical contributions, the managerial conclusions, the future work and the critique.

1.2 Lhoist history

> "Lhoist has been established in Belgium since 1889 and is well and truly embedded in the Walloon region. The Lhoist Group offers a wide range of mineral, calcic lime and dolomitic lime-based products. Their large range of reagents, as well as many years of expertise support a broad range of sectors such as: the steel industry, refractories, the environment, construction and civil engineering, agriculture, glass and chemistry." Lhoist website

Lhoist Group is a global leader in lime, dolime and minerals. With headquarters in Belgium, Lhoist is present in 25 countries with more than 90 facilities around the globe and employing more than 5000 staff.

Lhoist turnover was 2 billion Euros in 2013. The distribution of this turnover into different markets and regions is described in the next 2 pie charts. 1.1 1.2

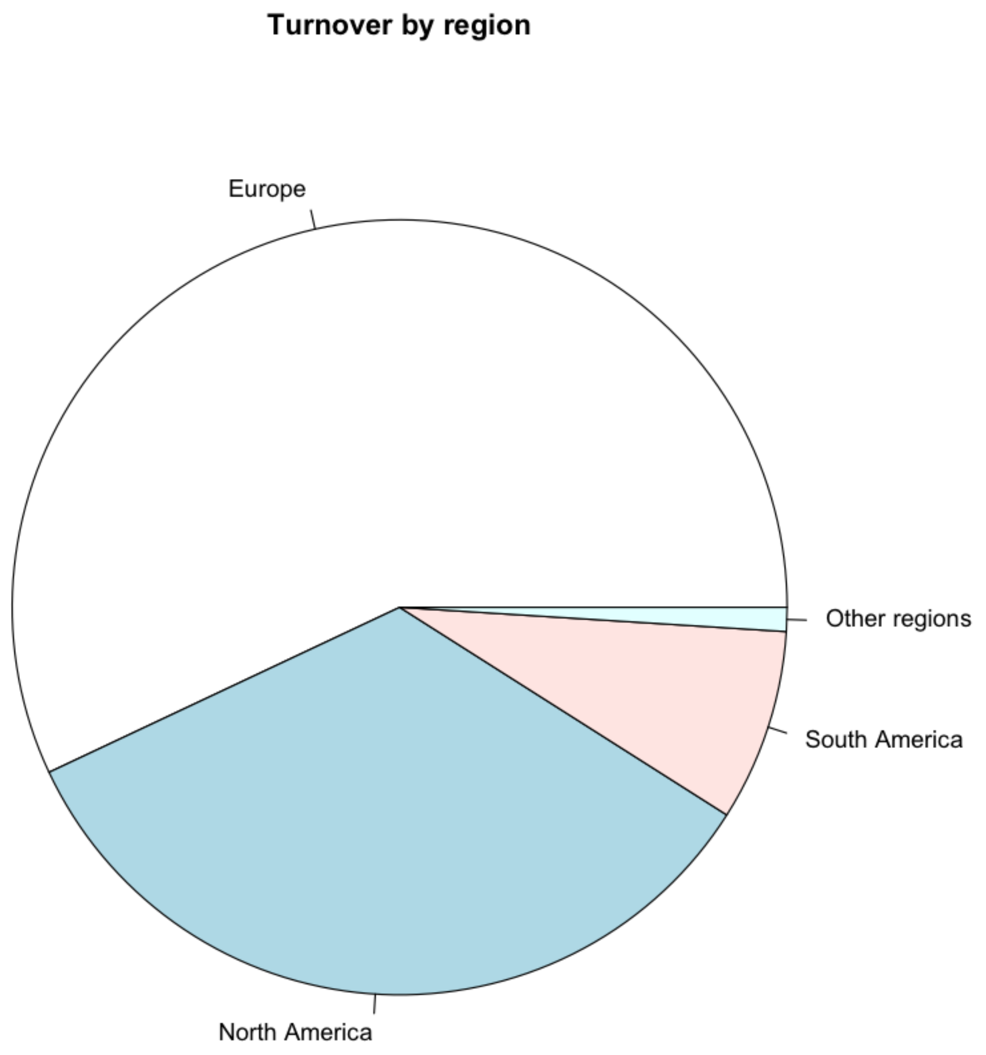

FIGURE 1.1: Lhoist world turnover by region in 2013

Lhoist started at the conclusion of the 19th century when Hippolyte Dumont took over the limestone quarry of Ampsin near Liege. The acquisition of a lime production plant in Hermalle-sous-Huy followed shortly. His son in law, Leon Lhoist expanded the company and started Lhoist Industries in the Marche/Rochefort region in Belgium and in Dugny-sur-Meuse in Northern France. Fast forward to the eighties, Lhoist group crossed the Atlantic to the USA. In the following decennium Lhoist expanded into Germany,

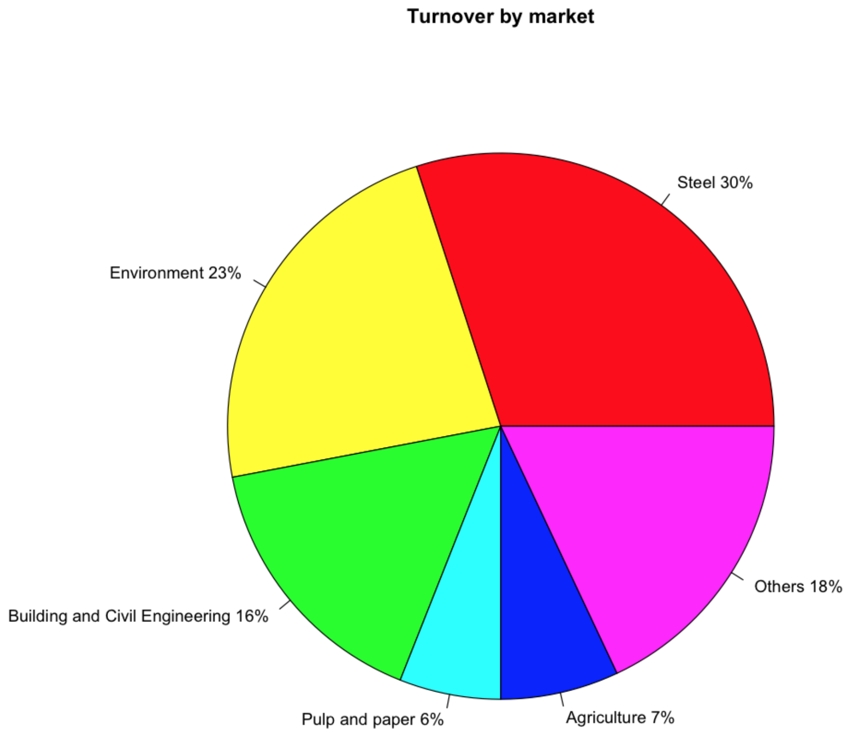

FIGURE 1.2: Lhoist world turnover by market in 2013

Scandinavia and Eastern Europe. The new millennium meant expansion into Southern Europe, Brazil, Russia and Asia.

1.3 Lhoist in Malaysia

Malaysia is located in the equatorial region in South-East Asia. The neighboring countries are Thailand to the North, Singapore to the South and Indonesia with whom it shares the Borneo island. The climate is a tropical rainforest climate. Port Klang, the main port in Malaysia is the 12th largest port in the world by volume handled according to 2012 statistics. All maritime traffic coming from the South China Sea passes through the strait of Malacca in front of the Malaysian shores.

Malaysia is the 14th most competitive nation on earth according to the IMB ranking. GDP per capita is estimated to be 25.830 USD. Malaysia's industrial sector amounts for over a third of the country's GDP. One quarter of the GDP is earned by petroleum oils and other derivatives. Malaysia has traditionally always been very dependent on natural ressources for it's development.

The seaborne lime market on the Indian ocean was considered as the most attractive entry strategy for Lhoist on the asian continent. As such Lhoist made Malaysia it's central hub in Asia. Today trade barriers in South-East Asia in particular and the Asia-Pacific region in general are such that Lime export is becoming feasible. The Asia-Pacific region is undergoing profound developments. Indeed the region accounts for 1/3 of the global growth in the world. A growing need for high quality lime is to be expected. Lhoist will attend the Asia-Pacific market from their base in Kuala Lumpur, Malaysia. To achieve this, an excellent supply chain strategy will be essential. Indeed, compared to Lhoist's traditional markets the geographical area deserved will be greatly expanded and the sales plan is undoubtedly transnational. As such the supply chain will be vastly more complex than Lhoist was used to in the past.

The story starts in 2007 when Lhoist acquired a limestone quarry nearby Tapah. The quarry has big reserves of excellent limestone. This supply will be used to satisfy the industrial demand of the rising South-Asian, Indian, Australian and African markets. Lhoist acquired Megah Jaya in October 2013 a lime production plant in Simpang Pulai, next to Ipoh. (You can find a map in the appendix.) In 2014 Lhoist started the construction of a new lime production site next to the limestone quarry in Tapah. Until this point in history there are no plans for regular hydration facilities. This greenfield project is expected to be completed by the second half of 2016. The greenfield project will be producing nearly exclusively for export. In early 2015 Lhoist bought over the lime activities of the NSL group. This means Lhoist acquired 1 lime production plant and 3 hydration plants. The lime production plant is located close to the Megah Jaya plant in Simpang Pulai. The 3 hydration plants are scattered over the Malaysian peninsula. Due to this acquisition Lhoist is now the biggest lime producer in Malaysia. Lhoist has plans to develop a knowledge center for the Asiatic development of the group in Malaysia. Their installation in Asia is determined in the longterm.

1.4 The lime cycle

Plants exist in many sizes and shapes. Most plants will have the following few stages of production in common. We will describe here the most complete plant. In the 1.3 you will find an illustration of the industrial process. A limestone deposit is usually covered with soil and/or vegetation, also called soft overburden and rocks also called hard overburden. The deposit needs to be stripped of this overburden. Limestone is a hard sedimentary rock. To be extracted the ore needs to be drilled and blasted. The ore then goes through multiple crushing, washing and screening phases. Where lime is selected and transformed into sizes for different applications. Different kilns will accept different sizes of stones. For example, a kiln runs on stone sizes 50-80 mm, bigger sizes are then being crushed to diminish their size and smaller sizes are being separated. In any kiln, too big stone sizes will make it difficult to have stones that are well calcined until the core. Small stones on the other hand will be more polluted because of their biggest surface to volume ratio. Only the surface is in contact with the burning fuel and thus impacting all the impurities. Size is important for the quality output warranty.

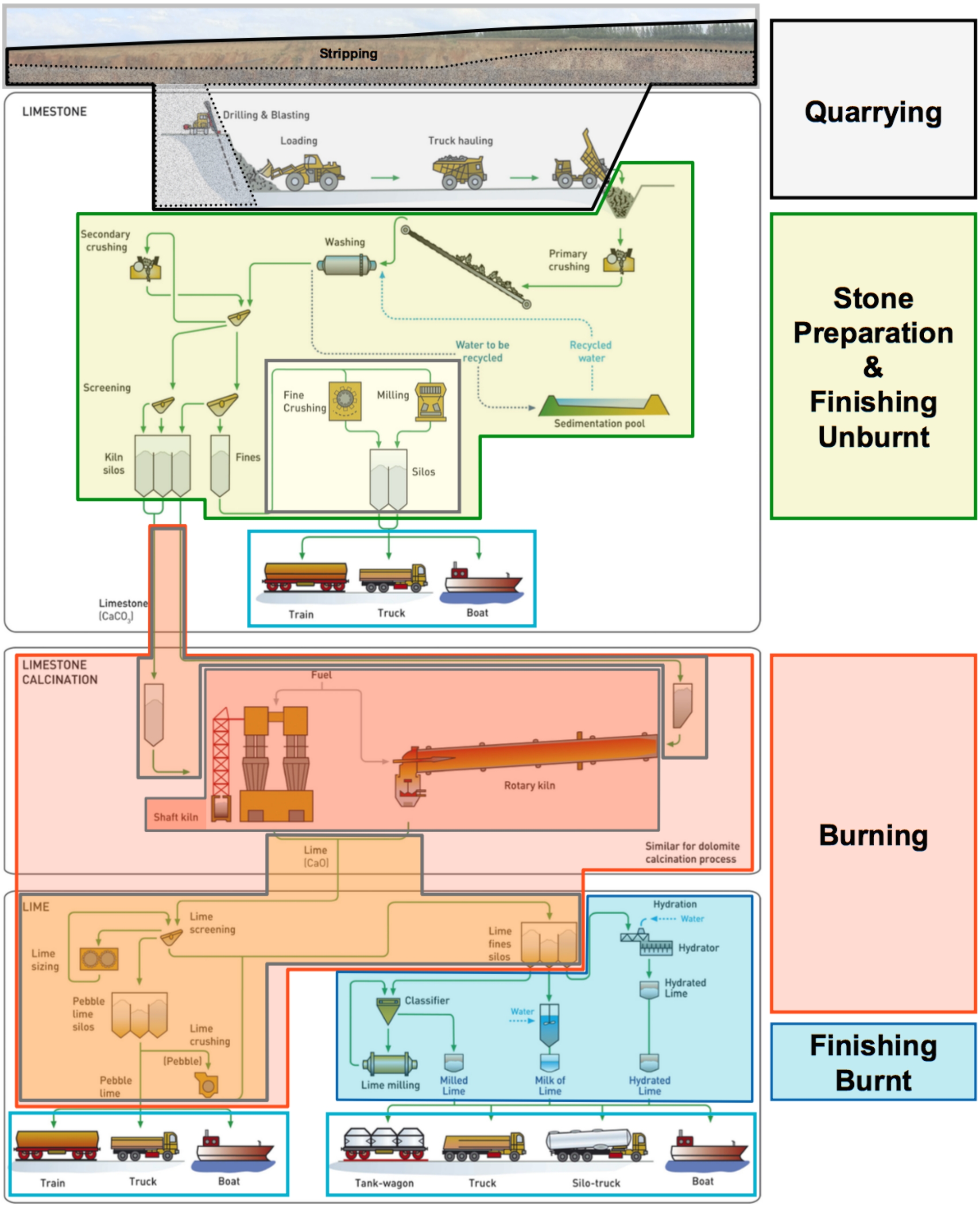

FIGURE 1.3: The Lime Cycle Industrially

Chemically, the reaction is relatively simple. Limestone is $CaCO_3$, it is heated until at least 900 °C. As a result CO_2 and CaO are produced. CaO is commonly called quicklime. Quicklime reacts exothermically with water. The resulting product is hydrated lime. $CaO + H_2O = CA(OH)_2$. Both dry and wet slaking or hydration are possible. Dry slacking results in a dry product because just the right amount of water is added in the process. In wet slacking a little more water is added, as a result the product becomes a slurry, sometimes called milk of lime because of the similarity with milk. The final step to the limestone from the beginning is the precipitation of calcium hydroxide into calcium carbonate (CaCo3) by absorption of CO2. The circle is closed. This cycle is called the Lime cycle, it is graphically explained in the following figure 1.4.

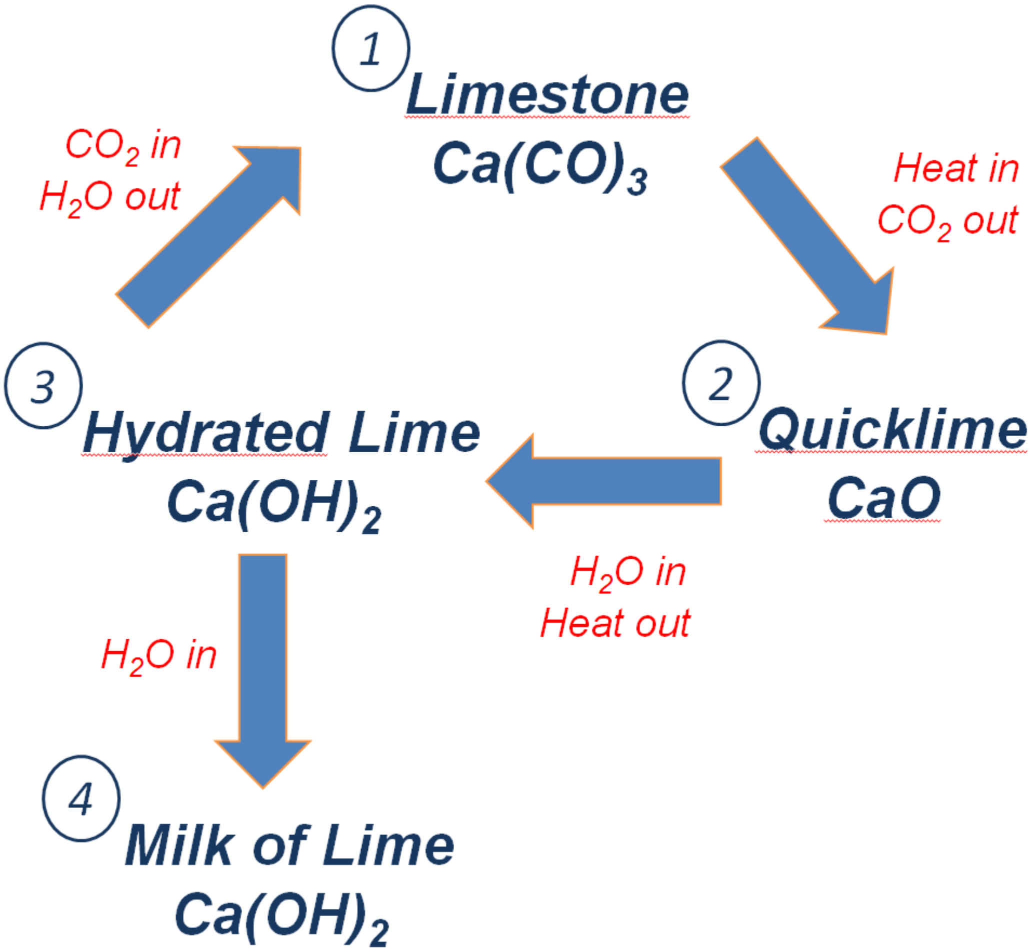

Figure 1.4: The Lime Cycle

Limestone can be calcined in different kind of kilns. This will result in different qualities for the finished products. Different type of kilns can result in needing vastly different size of stones from (2-150 mm). Kilns are heated up to temperatures of above 900 °C. As discussed the chemical reaction taking place in the kiln is: $CaCO_3 -> CaO + CO_2$. The lime (CaO) is then screened, especially for primary fines. Primary fines are the smallest particles that are created by friction in the kiln. Because of their higher surface to volume proportion, these particles have a higher concentration of pollution due to their contact with the fuels. An important metric for the quality of the lime is the available CaO. This is influenced by the pureness of the stones at the entrance of the kilns and by how well the limestone has been calcined.

Lhoist has a special kind of hydrate called Sorbacal SP. Sorbacal SP is a high surface hydrated lime. It contains a higher surface area and a higher pore volume compared to regular hydrated lime. This hydrated lime while more expensive to produce is more effective in most applications.

Lime is mostly being used for 2 reasons.

1. Lime reacts with acidic impurities such as Silica, Alumina, Iron, Sulphur, Phosphorus, CO_2 and HO_2.
2. Lime and Hydrated lime are both strong alkali. They are used to neutralize acids in many applications.

Markets will be discussed more in detail in Chapter 3.

1.5 Different qualities of hydrated lime

In the lime industry customers are usually willing to pay more for a purer product. Moreover most customers like to know what the non-pure components exist of. Some customers will be demanding for certain components, an easy example is the in the water treatment industry. Those customers will be very strict on polluting particles.

At extraction there are many different limestone qualities. Limestone is the result of a natural process, some very pure other a lot less pure. Run of kiln lime, i.e. the lime at the exit of the kiln, doesn't consist of 100% lime. As we discussed before depending on the calcination different impurities can be mixed with the lime. Furthermore if the calcination isn't complete some limestone can still be part of the lime. The limestone was not completely transformed because the heat didn't reach the core of the limestones enough.

When hydrating lime to produce regular hydrate, most installations will be able to split production on 2 qualities. In the hydrator there are air separators that permit to separate the hydrated lime and the lime that was not hydrated as well. Furthermore usually limestone will be able to be separated as well. This separation in fractions of different qualities makes standardization of the end product possible.

This means that even if you have lesser quality products that enter the hydrator you will still have at least part of the products of excellent quality. You will simultaneously produce a product of lesser quality and one of better quality. If you mix both end product you end up with the same quality as if you had no separator. With this kind of separator it is relatively easy to produce high quality hydrated lime as long as you don't mind having a lot of quality B compared to quality A. This levels the competition field. In the hydrated lime sales the quality of your mother lime (and mother limestone) is thus relatively less important. It is thus a relatively good market if you have relatively bad limestone or relatively bad production methods. You can modulate your end product characteristics and be conform to different product specifications.

1.6 Weight impact of hydration of lime

The weight of all these different products is significantly different. The client is mostly interested in the amount of CaO in the final product.

Limestone (CaCO3) has a molecular mass of 100, lime (CaO) on the other hand only has a molecular mass of 56. Hydrated lime (Ca(OH)2) finally has a molecular mass of 74. The client nor Lhoist are interested in transporting the process CO2 (i.e. the CO2 that escapes from the limestone during calcination) that results chemically of the lime production process. Any player in the market will thus try to limit the transportation of CO2 by calcining as close as possible to the kilns. Similarly for hydrated lime, hydration will be positioned as close as possible to the customer because of the extra volume and weight of transporting hydrated lime.

See more about this and how logistic trends are changing in chapter 2.

1.7 Supply chain model at Lhoist

According to Lhoist the purpose of the supply chain: >The purpose is to supply customers demand in quality, quantity and on time. It is crucial to look at all steps in the process starting at the quarry and going to the final customer.

Supply chain optimization at Lhoist happens at 3 time horizons:

1. The operational level: Which encompasses delivery planning based on real orders, quality, quantity and capacity constraints
2. The tactical level: Planning facilities activities based on forecasts

3. The strategic level: Capacity network design and reconfiguration based on long term forecasts. Robustness increases with the help of different what-if scenarios.

The approach is to simulate the lime and dolime business through a systematic modeling approach, integrating and optimizing the relationships between all key elements of the business.

1.7.1 Objective

The objective of supply chain management at Lhoist is to meet customers demand by providing the right product at the right time, while optimizing limestone reserves and financial results. The decision elements are the production levels of each production stage and, in fine, the opening and closing of different facilities and to determine the distribution to each customer. The objective is not, to minimize logistic costs,process cost drivers or production cost drivers separately. The approach used is the integration of the production and the distribution.

1.7.2 Parameters

The parameters are on the financial side: the costs of the different production steps in the different production facilities. On the industrial side: the different production yields and waste ratios, linked with the fatality of the production of co-products. On the sales side: Sales volume and prices, logistic distribution costs and the CO2 emissions on all kilns.

For each plant there is a Mass-Flow scheme. This describes the different diverging production schemes that are possible. This needs to take into account both grain size and quality. Indeed in many steps of the production when producing one product, different other products will be created simultaneously. For example when crushing bigger limestone to obtain medium sized limestone automatically you will obtain smaller limestone as well.

1.7.3 Constraints

The most important constraints are the natural ones. First the quality of the natural resources: This is mostly the purity of the limestone but also includes the concentration of all other elements that bonded with the limestone or the lime i.e. the sulphur, carbon dioxide and depending on the industry of other elements.

Second are the waste ratios, be it in stripping the minepit, or later in the process when separating ore from waste i.e. how much of the extracted stones is waste.

A third constraint is how the stone will split and produce co-products. The production process of lime is a diverging process. We start with the raw stones in the quarry and gradually we obtain a multitude of products in different sizes and quality. The splitting of stones happens with a certain regularity. Screening curves exist that will show the different proportions of grain sizes you will obtain at the exit of a kiln given a size at the entrance, this will also be influenced by the natural qualities of the stone.

According to how well the process is managed we can then get closer or further from these constraints. To illustrate this we can imagine a mine pit with 3 qualities. The layers of the different qualities are well separated into different strata. Without proper attention and selective mining all 3 qualities will be mixed. Unfortunately this could potentially give 3 worse qualities because each quality can be good in it's own distinct way. For example one can have low sulphur, one can have low Magnesium and one quality could have high Magnesium (i.e. it is dolime).

The technical constraints include capacity constraints, the available fuel mixes for a given kiln and the different recipes available to produce a final commercial product (Similar products can be produced by mixing different grain sizes or qualities and/or in different plants. Those are different recipes.).

Quality constraints include the reactivity of the product, the concentration of sulphur, carbon dioxide, of available calcium oxide and depending on the industry of other elements.

Commercial constraints are the product type requested by the customer, the quality requested by the customer, the frequency of orders, the order size and his preferred plant if any.

1.7.4 Supply chain in line with the global strategy

The most important factor for Lhoist is to have a supply-chain strategy that fits the company strategy.

A supply chain optimization plan can only be applied in accordance with the other objectives. It's important to always keep this bigger picture in mind. The supply-chain network optimum is not always what is implemented. It has to be weighted against the global strategy and sometimes different objectives need to be balanced. The first objective has thus to be weighted against the global strategy. In past projects Lhoist would use the logistics optimum as a strong reference. In Malaysia we will see that the density of the network is very different from Europe. Distribution and production thus have to be carefully weighted one against the other. They need to be solved together and to be integrated. To be responsive in the day to day operations Lhoist always defines how customers can be switched over to another plant if there is no capacity left. Lhoist calls this wheeling of the client. This redundancy is a strategic asset.

Because in the lime business you create a certain amount of byproducts, it's important to target diversified markets. If Lhoist would only target the steel market and their 20-60mm size demand. Lhoist would be left over with a lot of very small sized stones. Furthermore after extraction from the mine a significant portion of the stones cannot be used in the kilns because their size is too small. One solution is to have multiple kilns accepting different stone sizes. They should best be located geographically close in order to avoid transport of the carbon dioxide trapped in the limestone. (As a reminder $CaCo3$ has a molecular mass of 100 versus CaO of 56.) Markets for limestone are mostly road construction, aggregates or agriculture. Selective mining i.e. mining quality by quality allows you to select as early as possible. A typical Lhoist pit can have up to 5 qualities. In a typical plant we can thus end up with up to 100 products. Half of these will be linked i.e. producing one will fatally result in producing other products as linked product. The number of different products is relatively limited in Lhoist Malaysia compared to more mature markets. Furthermore at the moment the market is requesting to differentiate less on quality than in more mature markets. The markets for the linked products that Lhoist has difficulty to sell in other places is here mostly a non-issue. Lhoist can usually sell small sizes of bad quality to the Autoclaved aerated concrete industry. Optimum balance of valorized material is really important as we said but at the moment it doesn't seem like it would be a big issue. This could change when the market will develop.

Fuel cost is responsible for the main difference in price between different kilns. An optimal supply chain plan will caeteris paribus maximize the capacities on the cheapest kilns.

Supply chains can often find advantage in looking further than their direct customer. Integration with more downstream customers will be of interest for Lhoist Malaysia. Today the priorities are different and there is a lot of low hanging fruit that can be optimized before looking too far from the nest.

With most clients Lhoist has absolutely no view on their long term orders. People talk about random orders fluctuation instead of looking at season regulated flux. There would be benefits of trying to smooth out the client orders and understanding their order patterns. This might require understanding of Lhoist's clients for some but not for all. decent sales and operations link is missing. Today sales disclose the orders they have at most one week in advance this makes it very difficult for the plant managers to correctly run their kilns. Clients are ordering very late although for some of those customers for example in steel their production process is probably relatively predictable. Vendor Managed Inventory and shared capacity forecasts will be required in long term optimization.

Significant savings can be accomplished by shipping the right products from the right place and to make sure that we have a good mass balance i.e. that we don't end up with too much of one kind of product in one place or with too little in an other one. Balancing between plants, quarries and transport are important planning factors.

This for 2 reasons, in the lime business distribution is one of the most significant cost drivers. At Lhoist in supply chain on traditional markets they will usually start from the logistics optimum. The diverging production model is important because in the limestone business we start with maximum a few qualities in the mine, at every production step we create more qualities, sizes and finishes in the final products.

1.8 Research question

Lhoist Malaysia took over a competitor, NSL Lime in the first quarter of 2015. In the frame of the integration of NSL's assets and activities with Lhoist current and future operations in Malaysia, the question is raised how the NSL operational network could be integrated and if any centralization could be realized.

The acquired supply chain network is facing severe issues in terms of safety, ecology, reliability and quality of the products for some of it?s installations. Those installations must be either upgraded or replaced.

The rationale behind this project is the following: 1. There could be operational expenditure savings through different scenarios 2. In any case there will be significant capital expenditure. This important investment needs to be considered in an operational and commercial medium to long term strategy. 3. Total capacity increase: The sales team sees opportunities in the export market. This opportunity can not be realized given the current production capacities.

The research question of this thesis is: What is the optimal strategic production-distribution network for the Lhoist Malaysian lime operations in terms of EBITDA? The answer will be balanced on different additional sales scenarios. Having a stable balance will be as important as having a good balance.

Chapter 2

Methods, tools and background

In the second chapter we will describe the methods and tools that can be used to solve the research question. First we will describe production-distribution models and the state of the literature. Furthermore we will analyze trends about family businesses, non-renewable ressources, commodities and international logistics. Finally we will share a production distribution model applied on the research question.

2.1 Strategic production distribution cost models: Definitions

The problem we are facing is a typical production distribution problem. It is natural to have an analysis of how similar problems have been solved in the literature. We will start with definitions of production distribution problems in particular and supply chain management in general. We will then look at the origin of how the problem was tackled. We will analyse a number of models and find inspiration for models that could be applied to our problem. In the next chapter we will describe a model that can be used to solve the production distribution problem faced. Finally we will explore papers that focus on production distribution papers focussed in diverging industries.

To understand integrated production distribution system. We will first take a look where this field fits in supply chain management literature.

The definitions of supply chain management are wide ranging.

In 1958 in his famous book “Industrial Dynamics”, Forrester already argued that:

> “Management is on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of

> information, materials, money, manpower, and capital equipment. The way these five flow systems interlock to amplify one another and to cause change and fluctuation will form the basis for anticipating the effects of decisions, policies, organizational forms, and investment choices."

Because organizations are so linked, he argues that system dynamics influence performance of all functions. He already takes into mind not only the internal relations but also "the interrelationship between separate company functions and between the company and its markets, its industry and the national economy". He is one of the first authors that described the dynamics of factors associated with what is now called Supply Chain Management.

Supply chain management can be traced back to an interview with Keith Oliver in the Financial Times in the early eighties. The term became popular in the mid-90's from the end of the 90's operations managers started to use it in their titles.

Despite the popularity of the term: "Supply Chain Management" both in practice and in academia in recent years there is no clear cut definition. As can be expected the term Supply Chain is even more popular than the term Supply Chain Management (SCM).

According to Christopher in 2000 a Supply Chain is:

> "The network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer."

According to the APICS dictionary today supply chain management is:

> "The design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally."

Different authors will be more or less inclusive.

La Londe and Masters (1994) will put emphasis on the long term agreement aspect between firms and the sharing of demand and sales data.

Houlihan (1988) highlights differences between classical materials and manufacturing control and supply chain management. SCM will integrate rather than interface between the different parts of the business. SCM calls for inventories as last resort and not as first resort anymore.

Cooper et al (1997) defines SCM as an integrative philosophy to manage the total flow of a distribution channel. They will then argue that SCM takes a holistic approach and views the SC as a single entity with all departments having the same goal. Cooper at all (1997) finally argues that SCM is a set of beliefs of each firm in the supply chain that directly and indirectly affects the performance of all the other supply chain members and thus ultimately affects the overall supply chain performance.

More recently (2013) Fahimnia defines a supply chain as a an integrated system synchronizing a series of interrelated business processes in order to acquire raw material and parts, transform these raw materials and parts into finished products and distribute these products to either retailers or customers. Furthermore a SC facilitates information flow among various business entities such as suppliers, manufacturers, distributors, third party logistic providers, retailers and customers.

We will be relatively restrictive in our definition of SCM.

A supply chain is a network that consists of a set of geographical facilities, suppliers, plants and distribution centers. Through those facilities there is material flow from supplier, plant, warehouse and finally to the customer. Strategic supply chain management is the coordination of the different business functions. The goal is to bring the right amount of the right product at the right time as to improve the long-term performance of the company. This point of best long term performance should be a stable equilibrium rather than a thin maximum.

As some of the definitions above mentioned supply chain management will align different parts of a business(/es) into the same direction. The limestone extraction business will reap the most benefits of integrating the departments of production and distribution. This is why the integration of production and distribution will be studied in the following pages.

2.2 Production-distribution models

A production-distribution model integrates both the production and the distribution side of the supply chain to find an optimal equilibrium. In the following paragraph we give an example of single period, single product, single echelon and deterministic situation.

We imagine an ice cream plant, that can produce 2 flavors. Only one product can be produced at the time. There is significant rework between producing one or the other flavor because all the production equipment needs to be cleaned. The customers are grouped in 2 geographical distinct area's. Some live at the North Sea and some live in the Ardennes, there are economies of scale if we fill the sole ice-cream truck towards one geographical area. We have not yet invested in freezers that would allow us to have inventory at the plant. There is now a balance to find. Either we group production of geographically close customers which would imply significant rework costs or we group customers who require the same kind of product which requires larger transport cost. This is a typical, although simple, production-distribution problem. The problem can be expanded if we include the decision of the location of the plant or the size of the freezers for inventory keeping.

In this simple problem we can clearly see that by trying to decrease production (or rework) costs we will increase transportation costs. We already feel the intuition behind the reason for integrating those 2 kind of problems. Depending on the exact demand and costs a solution can be easily found for such a simple problem.

A strategic production-distribution model will try to solve such a problem. Such a model has an objective function: in the case of the ice cream example it could be minimizing the costs. Such a model has decision variables: in our example they would be for example how much do we produce of each variety before switching, how much do we load the trucks when shipping. And finally there are constraints: for example how much can be loaded in a truck.

A more complete problem is the optimization of a complete supply chain. In that case the problem is defining the following elements that will determine how the supply chain will run, i.e. te decision variables are: - the number,locations and capacities of the different facilities - the set of suppliers to select - the transportation channels - the amount of raw material and products to produce and ship - the inventory to be held

Applied to the lime industry the decision variables can be split in the following way: On one hand for the production:

1. The type of manufacturing plant, the amount of plants and their location.
2. The parameters of equipment that will influence the divergent process of the stones
3. The choice of suppliers
4. The amount of raw stone, and of finished products to hold.

On the other hand for the distribution:

5. The use of warehouses and the amount of finished products to hold there.
6. The means of transportation and which facility should serve which customer. This doesn't take away that customers cannot be served by other facilities.

We immediately feel that it's not easy to split the decision variables between production and distribution and that some variables will influence both processes.

If we apply this to facility location systems we get that, the goal is to have the right equipment in the right place to be ready to, given the different uncertainties, be in the stable equilibrium that will give a company the best long term performance.

Rather than have an unstable maximum it is better to have a large stable equilibrium.

2.3 Strategic, tactical and operational timeframes.

Production distribution systems exist in different time horizons. In the literature 3 are defined: strategic, tactical and operational timeframes.

As many terms, those 3 terms originally come from the military. Strategic decisions are those maximizing the overall value irrespective of immediate results. They are usually more long term. Tactical decisions on the other hand are those that achieve the greatest, immediate value. They usually have a narrow time horizon. The operational level in military terms is the conversion of strategic decisions into tactical decisions and deals with the formations of units. It makes sure that the resources are there for decisions to be converted.

Vidal & Goetschalckx (1997) give an example to clarify the distinction between strategic, tactical and operational planning for distribution: On a strategic level, a company will decide about the transportation mode, on a tactical level it will determine the fleet size. finally on the operational level it will decide of the dispatching of vehicles to certain locations. This is completely in line with the military vision.

Webb & Larson (1995) when discussing the difference between strategic and tactical inventory/routing problems note a major difference in solving the strategic versus the tactical problem. They argue that all possible realizations of the tactical problem must be, at least implicitly, considered simultaneously. It is worth noting that the inventory/routing problem has been a problem that has always been considered simultaneously more so than the production/distribution problem.

Other author classify the 3 levels according to the time horizons: Strategic level for time periods of more than 1 year, the operational level for short term decisions and the tactical level for everything in between.

When we apply this to production distributions problems: Strategic production-distribution planning corresponds to network design. It has long term impact on the supply chain and has a high risk impact according to Goetschalckx (2001).

2.4 Supply chain network design or strategic production distribution models

Many studies have been conducted about finding an optimal supply chain network, this is a real challenge for several reasons.

First of all the design of a supply chain network starts with the problem detection, it is followed by the formulation of said problem and ends with the solution of said problem.

Supply chain management at a strategic level is primarily about cost-effective location of facilities (plants and distribution center), the flow throughout the entire system and the assignment of capacity in each echelon, as discussed by Melo et al (2009). This is where any improvements in the supply chain will have the greatest impact. It is thus important to start by optimizing strategically before investigating shorter term optimizations.

In other words, a supply chain network design model helps managers conduct strategic planning for their company by selecting the best facility location that minimizes the total cost of the supply chain.

In other words bis, the multi product supply chain network design model helps with choosing the appropriate location of a new plant and distribution center as well as the distribution of the product. In such a model multiple products are competing for similar resources and will be selected according to the customer demand. A final test will always be to look if an answer is feasible and to test it against reality.

2.5 Integration of problems

There has been much research about production planning in the supply chain context on its own. There has also been a lot of research about distribution planning. In the literature many other problems have been discussed individually as well. For example inventory management and facility location models.

The next step has been to integrate these problems sequentially. The output of one stage is then the input of the next stage. For example, this could mean first setting the facility locations and then setting the inventory levels to keep in those facilities. In the same way in some models the optimized outputs of the production stage would become the input to the distribution stage. The problem with this approach is that in reality each decision not only influences the next level decisions but also previous level decisions. A unified body of those integrated analyses does not exist yet. Many authors have integrated many different problems. Classification of this literature body is thus not easy. Furthermore each author has made different assumptions.

Chandra and Fisher (1994) combine the production scheduling and vehicle routing problems to understand the value of coordination between these functions. They find that the integrated approach can result in a reduction of operational costs from 3 to 20% compared to the sequential approach. They observe that under certain parameters the analysis of coordinated functions may not be worth the effort to do the integrated analysis.

Benjamin (1989) in his prior research already hinted that the overall advantage of the integrated approach depends on a few parameters. The size of the advantage is dependent on the relative size of the setup and the holding costs at each of the supply and demand points. In cases where both the size of the setup and the setup costs are small it might be easier to optimize sequentially while still finding the approximate best solution. He stresses that simultaneous optimization is not always better.

Benjamin (1989) develops a heuristic that is limited to finding the local minima, it is based on Bender's decomposition. They develop an application relative to sourcing parts with 3 supply plants and 4 assembly plants. In their analysis annual production at each supply point is determined prior to the analysis. The decision variables they use are the order quantity from a supply point to a demand point, the number of units shipped annually from a supply point to a demand point and the production lot size. The objective function is to minimize total cost subject to the constraint that supply capacity not to be exceeded and demand be met. They describe a sequential solution, the simultaneous solution procedure is simplified with this sequential heuristic solution. The heuristic applies a Bender decomposition as in Bender (1962). He considers the simultaneous optimization of the production lot size problem, the transportation problem and the economic order quantity problem. His interest is to find optimal production sizes for supply points and order quantities for demand point.

Benjamin logically explains that unfortunately the relative advantage of simultaneous optimization can only be found by solving the problem both the sequential and the simultaneous problem. More research is needed to identify overall frameworks for which integrated analyses are beneficial and where the results will compensate the increased difficulty of the problem.

As many authors showed and for problems that are of a reasonable size it is now essential to look at production and distribution system simultaneously in an integrated manner. The more integrated supply chain are the more complex they become and the more difficult it becomes to get to an optimal solution. That is why models in the literature are only used to solve small to medium integrated supply chain planning models according to Barbarosoglu (1999). This paragraph and the previous do not mean that there is no middle ground, there are problems that are big enough to be interesting to solve in an integrated manner while small enough to be solvable.

2.6 Relevance to the limestone industry

Production distribution optimization in supply chain management has been in the spotlight of researchers and practitioners. The reasons are twofold according to Persson (2002): 1. The integration of production and distribution positively affects the profitability of the supply chain. 2. A quest for reduction of lead time and increase in responsiveness to market fluctuations.

Production-distribution integrated planning models are particularly relevant in the limestone industry, because: - Different production phases have significantly different distribution cost. This might be the most important reason. - Distribution represents a significant portion of the total cost to serve. - In the complexity of the supply chain lies a lowest cost option. - Lime is relatively low value per weight. An optimized distribution is thus important and will impact a big volume. - In most markets the customer attaches importance at the freshness of the product. Furthermore because of the volumes it is usually difficult to keep more than a few days of stock.

2.6.1 Origin

Geoffrion and Graves (1974) were one of the first to model the problem as a Mixed Integer Linear Problem (MILP). It is a multi-commodity distribution system design. They had a single echelon of distribution centers connecting production plants to customer zones. DC's are selected from a list of discrete potential sites. Supply constraints are formulated for each product and plant combination. Their objective was to minimize the sum of transportation and DC operation costs. Their model took capacity constraints into account for both DC and production. Transportation and modes of transport were not explicitly modeled. Furthermore the authors present a solution procedure based on Benders decomposition. This decomposition separates the problem at each iteration in easily solved linear problems, one for each commodity.

Geoffrion and Graves call this problem the optimal location of intermediate distribution facilities between plants and customers.

The model will select the optimal number of distribution centers out of all possibilities. Customers are assigned to a unique DC.

Many models have been formulated since. Some specific to industries others more general. In Goetschalckx and Vidal (1997) literature review of models for the strategic design of supply chains are baptized strategic production-distribution models. This name stuck until today.

Strategic supply chain decisions as defined by Thomas and Griffin (1996) are: decisions that may include plant or DC openings and closings, allocations of equipment to manufacturing facilities, selection of a location or locations for manufacturing of a new product or evaluation of changes in the flow of a particular product through the supply chain.

2.6.2 Complex supply chains

The figure 2.1 from Fahimnia (2013) is a good representation of the problematic of a complex production distribution plants.

Such a complex integrated production distribution model deals with a high number of variables. The model is multi period. On the production side it takes inventory of finished products, work in progress, overtime, outsourcing and regular production into account. In the warehouse it takes the inventory of finished products, the quantity to be received and to be shipped out. From the customer point of view it looks at the quantity of product backordered and the quantity shipped straight from the plant stock. This can be further amplified by the geographical reach of the supply chain. This might lead to inter modality or other restriction on legs that would be allowed for shipments. Or on legal restrictions due to trade barriers ranging from soft barriers such as different currencies to hard barriers such as import restrictions.

Finally the conflicting entity objectives better known as the human factor can be the most complex. Simplification of real life scenarios thus become essential if we want to obtain a solution. The level of simplification will be balanced by the value that can be obtained in function of the effort put in.

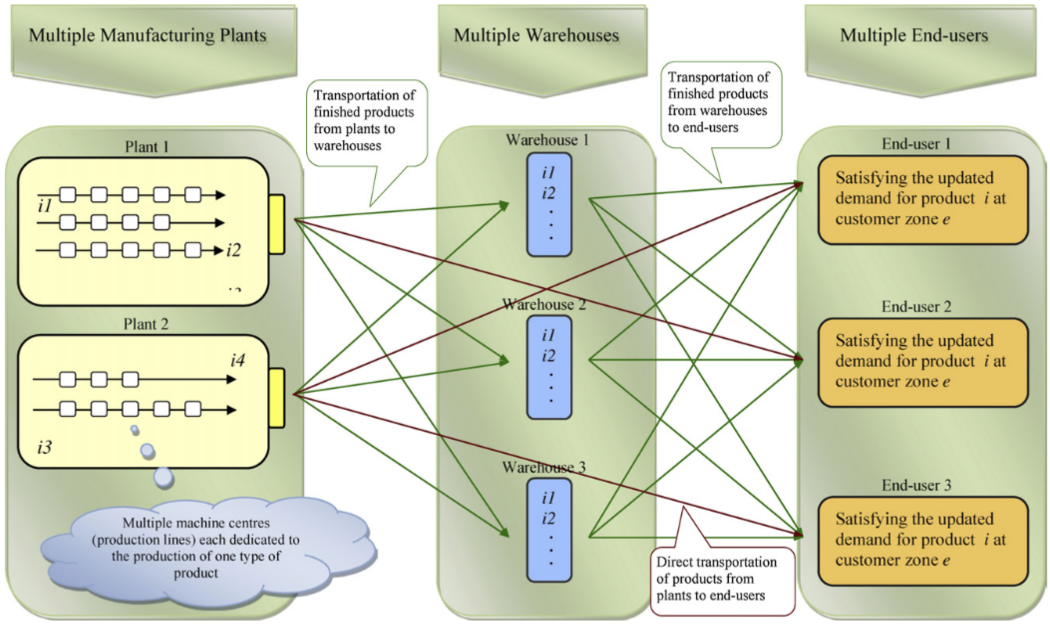

Figure 2.1: A complex real life integrated Production Distribution model by Fahimnia (2013)

Most of the complex production distribution models are classified as NP-hard problems by Thomas & Griffin(1996). Fahimnia (2013) is the only one doing a literature review based on complexity. The level of complexity is a good indicator of how much the authors simplified the reality in their model.

2.7 Multi-plant coordination in production distribution.

Bhatnagar and Chandra (1993) discuss coordination between different functions. They distinguish 2 big branches, they call them: "General coordination" and "multi-plant coordination". The first branch, General coordination is the attempt (sic) by firms to integrate decisions pertaining to different functions. On the other hand multi-plant coordination seeks to link together the production plants of several manufacturing plants which are part of a vertically integrated firm. Output from one plant becomes input for another one. They specifically address the nervousness between plants in this scenario. Which brings us back to Forrester (1958) with whom we started this chapter. They focus on multi-plant coordination which will be our focus as well as this is the most relevant to the traditional Lhoist setup. They define the property of coordinated multi-plant production planning problems as seeking to link together the production plans of hierarchical integrated manufacturing plants. The objective is thus to achieve better performance for the entire network, by coordination they can minimize total relevant costs and shorten the lead time.

In the “general coordination” branch Bhatnagar and Chandra (1993) distinguish three categories: supply and production planning, production and distribution planning and inventory and distribution planning. They give particular emphasis to the fact that in integrated production and distribution planning the 2 activities can be completely decoupled if there is sufficient inventory buffer. The pressure of reducing inventory and lead time causes a company to examine closer coordination. Sarmiento et al (1995) will raise this point a few years later and lament the fact that little research has been done on the closer interaction this requires in production distribution systems. Thomas and Griffin (1996) continue on Bhatnagar’s work in the general coordination branch and present a review of the works into these three categories. While analyzing the Production-Distribution coordination, they note that the limited research in the integrated problem. they explain this because of 3 reasons, the problems on their own are already tremendously difficult still many authors address the problems in sequence. Secondly those problems have been separated by buffers, which if they were big enough didn’t warrant to look into the problem, because both production and distribution can then be completely decoupled. Finally because different departments are usually responsible for production and distribution planning and the coordination in real life might be relatively weak.

2.8 Strategic model with hierarchical decomposition.

Cohen and Lee (1988) present a strategic model structure and a hierarchical decomposition approach. They model the different interactions between the supply chain functions. They divide the problem into 4; material control, production, finished goods stockpile and distribution. Those 4 sub-models are linked by means of local service targets. The resulting optimization model which minimizes the cost over all subproblems is intractable.

The heuristic they use works sequentially, each sub module is optimized and is then used as input for the next sub question. This framework permits to see how a given performance measure, influences the links between the different functions. The result of the heuristic was used as an upper bound. The model is thus in fact more of a resource deployment model given a certain logistics structure. For companies that already have a logistics structure this might be a helpful model and the variable fixing might not matter. In cases where there are lots of liberties it this model might be less interesting.

Chandra and Fisher (1994), whom we discussed about earlier when we discussed tradeoffs between the integrated and the sequential approach have a similar approach to Cohen and Lee (1988) for the sequential approach. In both cases the vehicle routing problem is solved with a heuristic. The procedure tries to improve the solution by combination of a shipment in current period with one to the same customer in the previous period. While observing capacity constraints of trucks and inventory balance.

The integrated procedure takes the solution from the sequential approach and consolidates shifts that can be made when the production schedule can be altered. The results indicate that that the value of coordinating both production and distribution increase when all else being equal: more production capacity is available, the planning horizon is lengthened, holding and setup costs decrease.

2.8.1 Literature reviews

Multiple literature reviews have been published.

Aikens (1985) presents one of the first reviews of facility location models. Of which the least complex is probably the simple uncapacitated model. At that time stochastic demand was not yet often taken into account. Aikens argues that this isn't a serious deficiency as deterministic demand is usually sufficiently accurate.

Bhatnagar et al (1993) present a review on models for multi plant coordination. They define 2 levels of coordination; general coordination. which adresses the the problems of integrating the different activities i.e. production, distribution and facility location. This is further classified in coordination between supply and demand, co-ordination between production and demand,and coordination between inventory and distribution. The second level of coordination deals with linking decision. And with multi plant coordination. They complain that single sourcing of customer demand by product is required for most applications but in many cases this makes the solvability very difficult.

Sarmiento et al. (1999) take a close look at integrated analysis systems that explicitly model logistics integrated to functions in production. They classify the literature by decision variable type; they are production, distribution, location, inventory or others. They also classify, and this is quite common in the literature, on number of echelons in the network. An echelon being one link in the supply chain. Seldom will one find a network with more than 4 echelon. Each additional echelon will make the resolution of the problem markedly more complex. Most authors who discuss multi echelon networks will thus resort to heuristics to find an approximate solution.

2.9 Facility location problem and extension

The number of possible locations is always restricted to to a finite set of candidate locations. The least complex setting of such a problem is the p-median problem. This problem can be extended with a term for fixed facility location costs. In both problems customers are assigned to the open facility that minimizes the assignment cost.

We can extend this problem with limitation on the maximum supply that one facility can provide. We then have the Capacitated Facility Location Problem. In this case the closest assignment property is no longer valid.

The common characteristics of those models are: single period planning horizon, deterministic parameters, a single product, one type of facility, and allocation decisions.

Several ways to extend those models have been studied in the literature. The multi period location problems. The inclusion of stochastic elements. Many parameters have an uncertainty associated to them, the most important one is future customer demand. The existence of different type of facilities with each a specific task and sequence. All sets of facilities of the same type are usually grouped together. A real life extension is to have multi commodity problems.

Saldanha-da-Gama et al. (2009) review the problem of facility location within the supply chain context. A general facility location problem consists of a set of spatially distributed customers and a set of facilities to cover customer demand which are linked together.

Saldanha-da-Gama et al (2009) identifies SCM as the process of planning, implementing and controlling the operations of the supply chain in an efficient way. Supply Chain Management spans all movement and storage of raw materials, work in process inventory and finished goods from the point of origin to the point of consumption.

They identify four main features that can be included in facility location models to make them useful for strategic supply chain planning: multi-layer facilities, multiple commodities, single/multiple periods, stochastic parameters instead of deterministic. Multiple facility layers do not always allow location decisions.

Most of the literature deals with single period problems and most of the literature deals with deterministic models instead of stochastic models. Uncertainty is one of the most challenging problems in supply chain management. But the literature integrating this is still rare. The uncertainty that is discussed in the literature ranges from customer demands, exchange rates, travel times, amount of returns in reverse logistics, supply lead times, transportation costs and holding costs.

He examines the planning decisions in addition to the allocation choices. Some variables that are commonly modeled are capacity, inventory, procurement, production, routing and the choice of transportation mode. Of those procurement, routing and the choice of transportation mode have not yet had a lot of attention in the literature. Only very few models allow to choose the transportation mode. Of those some allow several transportation modes in one link.

2.9.1 Two stage nature of facility location problems.

The most common robustness features are the minimax cost and the minimax regret. Minimax is always very conservative as it puts all the weight on the worst solution. It is also quite reckless as as it can produce quite poor solutions for scenarios other than the one with maximum cost. Minimax is mostly good in case the system needs to work in the worst case too. The other most common robustness measure is the regret of a solution. The regret is the difference between the cost of a solution in a scenario and the cost of the optimal solution for that scenario. Because minimax is applied to the regret it is not as pessimistic as the minimax cost. Regret can also be explained as the difference between the cost of the strategy and the cost of the strategy had we know what the future would be. Unfortunately most problems with minimax regret tend to be a lot more difficult than their stochastic counterpart because of their structure. As discussed in Facility location under uncertainty: a review by L. V. Snyder.

Problem of designing a distribution network that involves determining simultaneously the best sites of both plants and warehouses and the best strategy for distributing the product from the plants to the warehouses.

2.10 Supply chain evolutions due to mergers and acquisitions

Shapiro (2004) pleads to enlarge the scope of strategic supply chain planning studies and models. He examines three classes of decisions, supply chain, demand and corporate finance that should be evaluated together. Especially in problems where new investment or acquisitions are considered.

He laments that too often an analysis of the supply chain of a firm is aimed at minimizing the total supply chain cost of meeting a certain demand whereas the objective should be to maximize net revenues over varying sales. To realize this demand management decisions have to be included in the model. For certain commodities this can be done via price elasticities.

For a company that manufactures and sells commodities, whose sales are price driven, the supply chain network optimization model could be extended to optimise product mix decisions based on revenue functions.

According to Shapiro in challenges of strategic supply chain planning and modeling.

Melo, Nickel and Da Gama (2004) write an Excellent paper where they consider the creation of new facilities and the decreasing capacity in previous facilities versus the increase in capacity of the new facilities.

As a rule the capacity in new sites is zero at the beginning: K_j^1 and is strictly increasing over time: $K_i^t \geq K_i^t + 1$. While the opposite is true for the old facilities.

The relocation scenario also applies to the merger of companies. Previously separated supply chains are consolidated and a joint logistics structure needs to be planned. This entails shutting down some facilities and concentrating capacities in new locations. This model gives the option of gradually moving capacity from one old facilities to newer facilities. This might be an interesting model to pursue for Lhoist. This model is unfortunately only about the finished goods until the final customer. We also need to model the raw material movements. This will be possible with the addition of material balances in the following paragraphs.

2.10.1 Competition in Supply Chain Network Design

It is becoming prevalent that the competition in the future will not be company versus company but will be of supply chains chains mutually. On the other hand Rice and Hoppe (2001) argue that in reality instances of head to head SC competition will be limited. The more likely scenario will find companies competing and winning based on the capabilities they can assemble across their supply networks. They highly recommend all companies to analyse their network and to understand the networks of competition.

Farahani et al. (2013) judge that managers should consider both the network design as well as the competition from other supply chains in the market areas when designing a Supply Chain. First the manager needs to determine which kind of competition the supply chain is facing. In todays market, cost reduction only is not considered a competitive advantage for firms and their supply chain. Lack of models that take into account the sustainability in the ability of the chain to compete and its future income leads to large deviations from optimal supply chain network structures and may lead to significant losses.

Miles and Snow (2007) believe that knowledge management should be included in SC analyses. They argue that intangible assets like trust and collaboration are very important for the SC. They compare the different modes of competition the SC faces, the different customer behaviors and the factors on which the competition will focus.

Drezner et al. 2002 propose some heuristics for solving multiple competitive facilities location problems in his solid book. The objective is to maximize the capturing of the market share by all facilities from a same franchise together.

2.11 Material balances or Mass flow or Bill of Material

2.11.1 Arntzen

Include formulas tex. Arntzen et al (1995) describe a multi period global supply chain. It includes production, distribution and transportation costs as do most models. But it also includes duty cost, inventory costs and import restriction. Furthermore they use a global bill of material for all finished products. This global bill of material shows how each product can be fabricated in multistage manufacturing. In this global bill of material they define descendants and ancestors for each product. The global supply chain represents the fabrication stages, the recipes and the locations. Their model was used by a computer assembly company, they report multimillion savings due to the model. The objective function is a weighted sum of cost, duty drawback credits and time for processing and transportation. The activity time is the time it takes to perform a single operation in the supply chain. The weighted activity time is the sum of processing times for each individual segment multiplied by the number of units processed or shipped through the link. The weighted activity time is used in the objective function. The authors note that the duty drawbacks require a large number of duty constraints, furthermore these are exponential in the number of borders crossed by the global bill of materials. Arntzen works with hard and soft constraints. Their solver ignores inconsequential constraints while assembling a good solution and later corrects for those errors. Much of the computational burden is devoted to the flow conservation. To oppose this the authors employ row factorization which simplifies the calculations. The authors keep track of notable solving successes and build a set of most successful tuning parameters. It's quite rare that for authors to include any time measure in production distribution systems. The author doesn't expand on how he choose the weight ratio between cost and time. Any balance will change results dramatically and will be relatively subjective.

The art of solving their model lies in setting the right penalties for all their elastic constraint and to have a good row factorization. First they allowed an integrality gap of 0.001 percent but with a scenario system cost of nearly USD 6 billion some errors were as big as 16.000 USD. When one of their users saw this error, while the solution was advertised as optimal, he would lose faith in the entire solutions.

The Global bill of Material (GBOM) for all finished products shows how each product can be fabricated in multistage manufacturing. Each vertex represents a product and the facility creating it, each level represent a stage of fabrication. The GBOM is a generalization of the classical bill of materials in that all intermediate and final products are described together. It can be viewed as a collection of rooted arborescence with each vertex representing a product and the facility that represents it. Global Bill of Material vertices are numbered in preorder also called depth-first-search order.

2.11.2 Voudouris

Voudouris (1996) also constrains the material balances. Their work is applied to the fine chemical industries. They work with mass balances in time buckets. Only for explicitly defined recipes will those mass balances be allowed to be non-negative. i.e. for most indices the mass balance variable will be equal to 0. He explicitly defines the intermediate products in the different production stages. As does Arntzen he explicitly defines categories of upstream and downstream products. But Arntzen doesn't limit the number of echelons.

Arntzen (1995) focuses on comparing the cycle time performance whereas Voudouris focuses on flexibility of his solutions.

The BOM constraints represent the relationships between consecutive flows in a production path and indicates the amount of upstream flow that is required to maintain the downstream flow.

Voudouris goes 4 levels deep i.e. he describes the raw material, the intermediate product, the final product and the packaged product. The number of production stages is clear from the links between final products in one recipe and the starting products in the next one. A lot of the recipe information is contained in the dyads used. (Dyads are pairs of indices.) They must belong to one of the recognized production paths of the process. Voudouris (1996) explicitly checks if the mass balance is kept by means of inventory mass balances. This is surprising given the chemical industry and the fact that in his transformation processes there will probably be some mass leaving the system, CO_2 for example.

A big problem with both the Voudouris and the Arntzen model is that for a large scheduling horizon the total number of binary variables will reach a prohibitive size. Voudouris argues for reducing the binary space by exploiting manufacturing rules. e.g. production of the product within a week of sales and thus of distribution.

Voudouris addresses flexibility in the objective function. Voudouris explicitly models flexibility. The flexibility of the plant to absorb unexpected demands and in this way increase the responsiveness of the plant to changing demands. Measure of flexibility is the integration of the slack in resource constraints over the time horizon.

Many manufacturing rules are implemented by fixing binary variables. The number of binary variables are dependent on the number of time periods that are considered. This means that for large scheduling problems the size can become prohibitive.

2.11.3 Bredström

Bredström et al (2004) explore 2 methods of handling recipes in their model. The model was developed for the pulp mill industry. It is thus divergent as the lime industry. Their model goes out of the fact that for each period each plant will only produce according to one kind of recipe. Furthermore they limit the model to maximum one final product for each recipe. The cost is fixed during each time period. They develop 2 models:

The first one uses variables representing production plans for individual mills covering all 3 months they are evaluating, one variable gives one production plan. The production plan specifies which recipe is to be used in each time period. Their approach to solve this model is a column generation model. They allow aggregation of time periods to allow the model to be solved within time limits.

Their second model describes the supply chain problem as a Mixed Integer Problem Model. They introduce binary variables that describe which recipe is used at which plant during which time period and variables that indicate if they recently changed recipe in the plant. They strengthen their linear relaxation and decrease the size of the branch and bound tree by adding valid inequalities. The valid inequalities they add are: Total production must exceed total consumption at all times. The consumption of products and work in process up to a certain period can not exceed the available assortment during the corresponding periods.

The resolution of the problem can then be done via branch and bound on the binary variables. They use both variables describing the recipes used in each time period and variables representing successive changes of recipes.

Bredström et al. model the production, the distribution and the storage of the product.

They have a few constraints specific to the logging industry they are working in. Each pulp mill uses exactly one production plan. Inflow of logs doesn't vary more than 10% from a fixed level. There is a maximum inflow level for each mill. In the lime industry similarly there are minimum utilization constraints for the kilns.

The model allows to delay the distribution, but at the cost of a daily fee. This gives a more robust model as demand and production volumes don't always align. The model allows to find optimal production plans, optimized flows and storage for the supply chain.

2.11.4 Divergent industries: Canadian Lumber industry case

Vila (2004) writes a model applied to the Canadian Lumber industry. As is Bredström's (2004) is is also diverging.

The paper gives an interesting perspective with a directed multigraph of production and storage activities. The divergent nature of the process is modeled by associating one-to-many recipes to each production activities. The objective is to maximize global after tax profit. The model would be fully applicable to the Lhoist supply chain if it wasn't for the stock keeping. Villa et al. go as far as including seasonal stock. The industry they focus on is the softwood lumber industry.

They use an acyclic directed multigraph to explicative the relationships between the several products. This is a conceptual representation of the manufacturing process and is independent of the current physical implementation. A process multigraph describes a multi-echelon distribution network. Each recipe is characterized by one input product and a set of output products. One to one recipes are used for process yield.

An important aspect of both this model as the Lhoist model is that product substitution and alternative production recipes can be used to allow a better match between sales and production. This can lead to more expensive solutions but allows to be more flexible.

2 other papers in the diverging industry worth a read are Dauzère-Pérès (2007) with a case in the calcium carbonate slurry industry and Chen and Wang (1997) with a case in a steel production plant.

2.12 Global Supply Chains

According to Friedman (2005) in his book: the world is flat. There are three stages of globalization. In the first phase the countries and governments drive the globalization. In the second phase multi national companies start to globalize. This results in SC outsourcing their noncore activities and building networks with strategic partners. Today we are in the third phase with people empowered to act globally. Because supply chains are wider ranging it makes sense for models to reflect this and to be more global as well. In this paragraph we will discuss models that reflect this particularly well.

Supply chain models can be both global as local. In an international scenario the flow of information and cash are more difficult to model. If we want to model as true as possible we should take taxes, exchange rates and other trade barriers into account. Sources of instability should then also be taken into account. Government stability and general infrastructure are critical issues for for the strategic design of a global supply chain. They are very difficult to include in mathematical models. This is also true for other global market uncertainties such as exchange rate fluctuations and price variability.

Cohen and Lee (1989) develop a model that supports resource deployment decisions in a global manufacturing and distribution network. They maximize after-tax profits in all countries together. On top of the variable and fixed costs for procurement, production and distribution they model the transfer pricing, tariffs, duties and other cross border legal aspects.

They consider fixed costs for transportation, the model could be upgraded with detailed vehicle routing to be applicable for Lhoist. The problem is a mixed integer, non-linear program. They describe different resource deployment strategies for each of the primary supply chain stages. An example would be choosing between a centralized plant and and a scenario where plants serve customers in a specific region. The high number of 0-1 variables forces them to solve hierarchically. Because most firms would already have a logistics structure some variable fixing will definitely happen. The problem would thus be simplified.

Additional aspects include financial aspects, risk management aspects and other aspects. Financial aspects include international factors, incentives, budget constraints. Financial factors have a strong impact on the configuration of global supply chains. we have taxes, duties, exchange rates, transfer prices and local content rules. The incentives include financing and taxation incentives.

Meixel et al (2005) in his literature review describes global supply chain design. He argues for inclusion of external supplier locations in addition to the internal manufacturing. Indeed this makes sense for problems where the suppliers play an important role. This isn't the case in the lime industry.

Prater et al (2001) find that the degree of exposure of the supply chain is influenced by the number of geographic areas covered by the supply chain, the number of transportation modes and their speed, the number of political areas and borders, the technical infrastructure and the environmental issues. As the exposure of the supply chain increases, agility decreases. Some trade-offs have to be made. They recommend to focus on a few agile aspects and not to strive to comply totally with the initial definition of agility.

2.13 Modeling and simulations

Longo et al (2007) defines a modeling and simulation approach for studying supply chains as flexible and parametric for evaluating different scenarios. Making a new simulation needs to be time-efficient even when the supply chain is complex and is comprised of many stages and/or products. Making a new simulation needs to be highly repetitive. After testing a simulation model Longo concludes that using simulation tools have big potential in terms of decision making tools for analysing a supply chain.

Terzi et al (2004) in their extensive literature survey about the use of simulation in supply chain management show that network design is a common application. They argue that most simulations are done intra-company. Which makes sense because of the ease of data access.

Chang and Makatsoris (2001) highlight the main benefit of simulations as allowing the evaluation of operating performance prior to system implementation, it enables powerful what-if analyses leading to better planning decisions, it permits the comparison of various operational alternatives without interrupting the system. It permits time compression to make timely decisions.

2.14 Business process re-engineering and SCM research.

Thomas and Griffin (1995) note that more generalist business literature and authors such as Porter or Hammer and Champy and their Business Process Re-engineering are very complementary with the SCM research literature.

Hammer's most famous idea is the "The superefficient company" (2001). He pleads to consider a redesign of processes by eliminating duplicate or unnecessary activities.

Porter, famous for his value chain (1985) focusses on the linkages between and among the activities.

Both process re-engineering and Supply chain management have a lot in common, they analyze the value-added implications of all business related activities.

O'Sullivan and Geringer (1993) present an interesting idea of natural versus constrained supply chains. The natural supply chain is a theoretical ideal of all the necessary value adding activities. The contrived chain on the other hand is "an imperfect implementation of the natural value chain". They stress the importance of keeping this natural supply chain in mind when re-engineering the contrived, real supply chain.

Verter and Dincer (1995) highlight a problem that in the industry management first identifies feasible configurations. Determining these configurations in itself is a problem by itself that would deserve more research.

2.15 Lime a non-renewable resource

Lhoist is a mining and minerals company. Lhoist extracts non renewable resources from the earth; limestone and dolomite. These resources are present in vast amounts in the earth crust. They are only extracted when they are concentrated enough to make it economically viable. These concentration processes tend to take an extremely long time. In that sense limestone and dolomite are not scarce but the deposits were the concentration makes it viable to extract high quality in a economically viable way are scarce. Limited economical resources availability and high shipping costs (or low value to weight ratio) have a big implication on a strategic level. It is possible to have a high share of the available resources in one hand and thus to drastically limit competition. This implies that even if someone adds pressure onto the market, if the demand is big enough this will not have an influence on the other prices. If the demand is relatively small a long term player can decide to temporary close one of the mines and to decrease the supply to open it back in better times. Lieberman (1988) confirms the preemption of input factors and locations as mechanisms that promote first mover advantage. Once dominant on a mature market it is likely that a company will stay dominant. The first mover advantage in natural resources is further described for the nickel industry by Main (1955) and is historically proven as a realistic advantage.

The lime industry is capital intensive. Continuing Capex and maintenance represent big parts of yearly expenses. As in the glass industry, set up costs are big and the equipment suffers a lot in case of halted production. Indeed investments are relatively important to build modern lime kilns. Those barriers to enter this market make the industry more resilient to competition. Slow technological evolution and slow pace of market evolution are the market conditions where first movers advantage gives the best conditions for establishing a dominant position according to the Harvard business review: “The Half-Truth of First-Mover Advantage”. The technology is relatively mature in the lime industry. The market conditions around the Indian ocean on the other hand are expected to be relatively fast evolving in the following years. Both volumes and quality demanded are expected to rise in the following years. If a company has the resources to grow with the market a first mover advantage is expected to be of benefit in the long term in a situation with turbulent market conditions.

All of this together adds up to a relatively profitable business especially if one looks at long term profits and one has a lot of investment power.

Because of the relative scarcity of those resources Lhoist optimizes all extraction of stone. We can imagine a theoretical case where the price of lime drops significantly. Lhoist would then be able to decide to reduce their extraction and sales and to pick those up again when the price stabilized back to interesting levels.

As in most industries that start from a natural product for example all extractive or logging industries, the production process at Lhoist is diverging. This gives a reverse production structure compared to most industries. There is a diverging flow of material contrary to the more usual converging flows. This means that we start with one or few products at the beginning of the process and end with several more at the end. If a desired end product has a certain quality and a certain size, inevitably other qualities and other sizes are produced. The more specific the quality and the size of the desired end product the more co-products will be produced at the same time as by-products. The more production steps we have the higher the amount of different co-products. Not all co-products are equally appreciated by the market. As we will see later, Lhoist will try to maximize the global margin over the amount of limestone extracted, this means that it is important to valorize every co-product. The strategic objective for Lhoist is to maximize long term profit per ton extracted.

As an example limestone fines that are burned result in particles with a higher proportion of sulphur dioxide and other pollutants, this results in a product that in most markets is difficult to sell. Due to the way kilns operate you cannot completely eliminate this co-product but you can try to influence the proportions. For example, by using crushing methods that result in less fines.

2.16 A Supply Chain adapted to the product

Depending on the market uncertainty and the supply uncertainty other strategies will be used. Through out the world Lhoist has markets with low supply uncertainty and low demand uncertainty. In those markets the differentiator is mainly cost efficiency. In markets with high supply uncertainty on the other hand it is important to pool and share resources. In markets with demand uncertainty, it's important to be flexible and responsive. This is mostly the case when marketing innovative products.

Fisher (1997) made the following diagram 2.2:

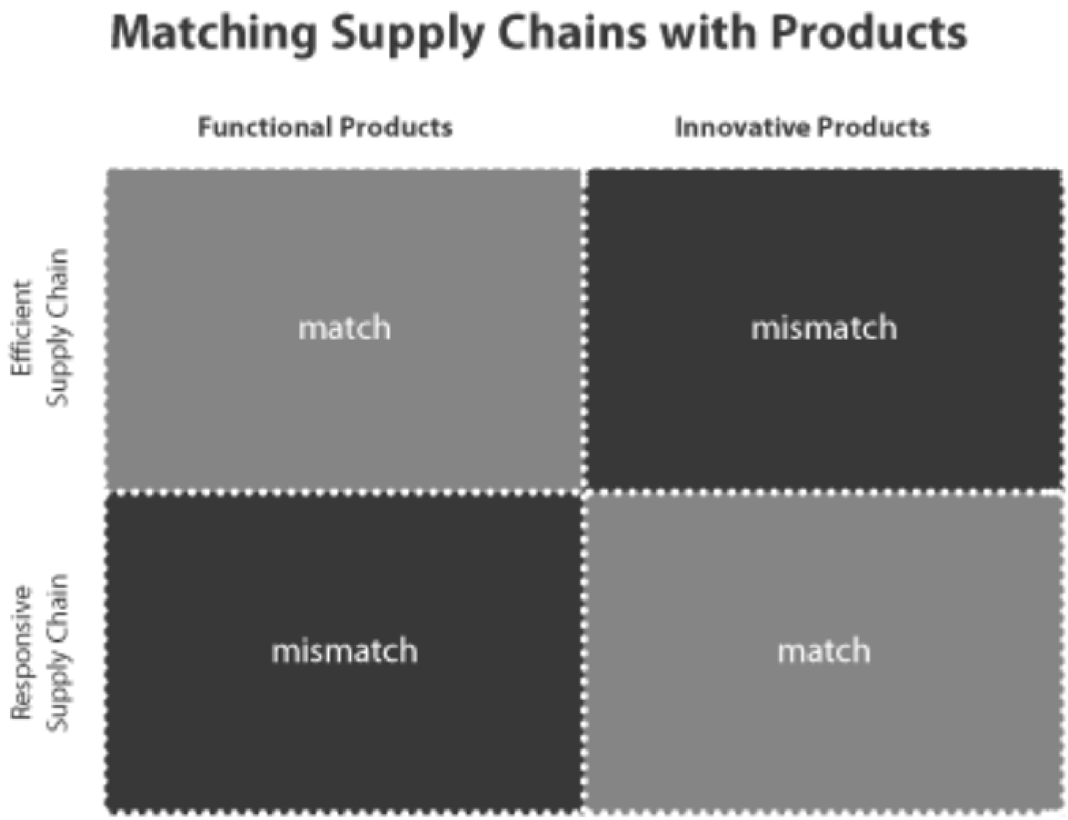

Figure 2.2: Matching supply chains with products from Fisher (1997)

In the Malaysian market Lhoist has relatively low supply uncertainty and relatively high demand uncertainty. This has multiple explanations.

On the supply side: The quality requested by the customer is relatively low thus as long as we don't have a major problem in production it is not too difficult to get to a quality we can deliver. Age-ing of product is less of an issue in Malaysia, despite very high humidity levels and despite stock keeping is seldom done in silo's but mostly in big bags. Historically dumping of fines has less been an issue as in Belgium. Finally lower quality products or grain sizes smaller than the steel industry demand already have relatively significant demand.

On the demand side: The lime market is over-capacitated in the Malaysian area. There is no import, and 30% of the production is exported. Because of the supply glut, competition is high, furthermore since Lhoist's' arrival on the market a price competition started. The customer is not used to share his production plans and thus his lime demand. Except for a few contracts, there is thus a lot of variability and no clear projections of the customers need. Furthermore our product quality is not aways as stable as it is the case in more mature markets. With very stable quality it is possible to lock in the customer because the production process can be fine tuned to this quality. Some customers will prefer a little lower quality in exchange for improved stability in the quality over time.

As the products that are sold in Asia, except in Singapore, are mostly low functional products and that in the future all plants will be up to Lhoist standards traditionally one would expect to move to an efficient strategy. I.e. a strategy where cost differentiation will be the most important factor. Positioning lime products out of the commodity scope by tailoring to customer needs, might take pressure of the basic price competition. Convincing customers, that having better quality lime will significantly improve their production process could bond customers to specific supply channels.

In this context hydrated lime is a difficult product to commercialize. This is a product where having good quality is less dependent on quality of the limestone and the calcination process. Differentiation will thus automatically be more on price. Especially if the hydration is done away from the customer site. When offering extra services as customer on-site hydration, which will guarantee the best possible fine tuning of the hydrated lime to the customer requirements then we can start to exit this commodity trap.

An important addendum is about production capacity. Lime kilns can not operate too below their optimum capacity. Furthermore they are damaged when repeatedly stopped. All the other equipment on the other hand can be stopped at will.

In general different products and/or markets will have different demand and supply uncertainties. It is thus important to use a mixed set of strategies for production, product specialization and commercially.

According to the article in HBR the root cause of poor performance in Supply Chains is a mismatch between the types of products and the type of supply chain strategy used.

In the Hydrated lime business a very different approach will be taken for the water treatment industry or for the agriculture industry.

2.17 Lhoist a family owned business

Lhoist is a family owned business. This influences the company on a profound level. The vision of the company is much more longterm. Decisions are being taken that will only have a return on a very longterm basis.

For example Lhoist had a few employees in the Malaysian peninsula before starting a significant investment, this has allowed them to have profound knowledge about the market. In another country in the same region where Lhoist was thinking of starting their Asian venture before was decided upon Malaysia there were more than 10 employees to gather market intelligence. I believe those employees contributed significantly to the success in Malaysia. They acquired some intuition that can only be acquired over several years.

This is discussed by Carlock (2001) concerning the commitment and unity that family owned businesses share. This is because their owners see themselves - and their heirs - as in business for the long-term. On the other hand he explains that as a family business you not only have to plan for the business but also for the family. Emotions in a family owned business can run high and need to be taken properly care of. In a family business he stresses the importance of taking rational decisions. And to be able to distinguish between family affairs and business decisions.

Finally he explains that the family probably has a bigger sense of responsibilities over the employees because the name of the company is often immediately associated with their own name.

2.18 Lime a commodity

Most of the products sold by Lhoist are commodities. Lhoist values Research and Development for new applications of their products as can be seen by the many product developments they presented over the years. Many of those have been patented and assure Lhoist to have a competitive advantage. Despite this R&D Lhoist' products are mostly considered as commodities. To keep healthy margins and to escape the commodity trap Lhoist gives importance to tailored customer service.

To avoid the commodity trap there are 3 possibilities according to Quelch (2007):

1. Innovate: This is something that Lhoist tries to do with their extensive Research and development. They have a few patented products that were elevated out of the commodity sphere.

2. Bundle: Lhoist will nearly always sell their products delivered at the customer place. They thus bundle the transport with the product. Lhoist has a few patented products. Clients in one of the markets Lhoist serves usually buy both regular hydrated lime and a special patented hydrate. Lhoist bundles both and convinces the customer with the savings of using both products together.

3. Segment: Some customers are less price sensitive than others. For those customers application expertise can be a differentiator. In mature markets Lhoist has differentiated their products a lot. Depending on application names and packaging change. A very interesting read on the segmentation of products in a similar industry are the different articles written by François M. Jacques, former vice president of marketing of Lafarge who started the marketing division within Lafarge.

The Malaysian lime sector produces 130% of the total local lime consumption. Interestingly what can be expected to happen in a commodity market with no capacity problem is happening in Malaysia today: Frequent price cuts.

John Quelch recommends:

1. Compensate the salesforce based on profit margin instead of on volume. This point needs specific attention ant motivation of the salesforce

2. Trim costs and acquire competition (with profitable customers) to extract maximum economies of scale. LMA today is the leader in Malaysia. But the market is over-capacitated.

LMA plans to export a significant portion of their production in the future. The South East Asian market is not over-capacitated. Quite the contrary, and it is expected to grow significantly in the following years. This duality between a local market where the price competition is high and an export market where the price competition is expected to be lower but with a lot of uncertainty.

2.19 Logistic impact on export:

At least ninety percent of the world non-bulk cargo is moved by containers. Of those the majority are 40-foot containers. The difference between 40-foot (FEU) and 20-foot (TEU) containers is two-fold. On one hand the volume as the name suggests is a little more than double. On the other hand the weight allowance is only 25% more of the net weight. TEU can carry a net load of 21.6 tons, FEU can carry 26.5 tons of net weight.

For lime LMA uses 20-foot containers. Lime is heavy cargo. It hits the maximum weight in a 20 foot container. Today there is no benefit of using a twice as expensive container allowing only 25% more lime.

Hydrated lime has a density of 0.6t/m3 compared to the 0.9t/m3 for lime. For comparison purposes it is common to talk about quick lime equivalent this means that we bring everything back to the amount of quick lime used in the production. For transportation the quick lime equivalent pricing will increase for 2 reasons: You add 28% of weight due to the water increase. And you add 50% of volume due to the lower density. With creative solutions it's possible to workaround the volume increase but not around the weight increase. We are already hitting the maximum weight on all transportation modes for quick lime.

To conclude this paragraph assuming transportation cost increases linearly by the distance and transport costs increase by weight and volume. It is optimal all else being equal to 1. Have the kilns as close as possible to the mine. This will reduce the amount of trapped CO2 transported. 2. Have the hydration plants as close as possible to all the customers. This will reduce the amount of water transported.

2.20 Design of a strategic production distribution model applied on the research question

None of the production distribution models we found while doing the literature review is really applicable on our problem. In the following chapter we will develop an integrated production-distribution model that is applicable on the case study we develop in appendix A.

2.20.1 Problem formulation

The Lhoist complete supply chain, from mining of limestone to the delivery of lime-products involves many important steps. A huge amount of lime is produced, the savings generated by careful planning of both production and transportation can be significant. This section begins with a detailed description of the supply chain. To solve the problem described in the introduction the theoretical way would be to use a linear optimization model where the production and the distribution is integrated.

In this chapter we will design a mixed integer program that can be used to solve the network design problem of a multi-echelon supply chain with diverging production and with logistics terminals. The production will be implemented according to recipes both one-to-many, many-to-one and many-to-many. Transport cost are dependent on the product and the distance, production facilities are capacitated. Fixed costs are implemented for the plants.

2.20.2 Components of the supply chain: Introduction to model

A traditional supply chain in the lime industry consists of several mines. Several plants, each plant will consist of one or several kilns, several crushing equipments, several equipments to sort or modify stone sizes. The network is usually relatively dense. As such customers are never far away from a plant.

In most geographies Lhoist is supplied from several mines. Most of those mines have stones of multiple qualities. Qualities are dependent on natural availability and segregated based on customer requirements i.e. Lhoist defines a quality only because the customer requests it. Lhoist very seldom procures lime or limestone from foreign sources.

The limestone is crushed on site into different sizes. Different kilns will use different sizes of limestone. And will thus create different size distribution of lime pebbles at the output. Manipulation of the raw material will create fines. As explained in previous chapters, we want to minimize the amount of fines in the kilns.

Raw limestone can be stored well, furthermore there is habitually no inventory limitation on site. There are thus virtually no costs associated with this storage. Lime on the other hand is traditionally relatively difficult to store. Lime reacts with moisture and CO2. The lime needs to be protected from the air to prevent re-hydration and re-carbonation. It needs to be protected during storage in expensive (relative to the value of the finished product) silos. Finished product in big bags can be stored a certain amount of time but it is not a perfect solution. This isn't being done in Europe. It's practiced in Malaysia, this doesn't work for long term as due to the high humidity, product in big bags suffer a lot after 3 months of storage, this period should be taken as an absolute maximum shelflife.

As we explained in chapter 1 hydration in a controlled environment to obtain hydrated lime is traditionally done close to the customer. This saves costs in terms of logistics as we are not transporting the water.

In Lhoist there is a concept called Mass Flow, on which we briefly touched in chapter 1. The mass flow describes how the different raw limestone are transformed according to size and quality into products that can be sold to a final customer. As this is an extractive industry it is important to maximize the use of all stone sizes and qualities.

One of the goals is usually to have a balanced mass flow, meaning that all products are being valorized by the customer. Limestone is a finite resource the EBITDA need thus to be maximized per extracted ton of stone.

All transformations (in the mine, in kiln plants and in the post processing) can all be modeled following a recipe. Even when crushing a stone of a specific quality a very clear decomposition pattern of sizes appears.

In each plant several operations/transformations are occurring at the same time. But in each machine only one transformation can happen at once. The transformations are codified as recipes. Most machines can produce following a few different recipes. The set-up costs are usually relatively low. The recipe changes are thus modeled as free.

A recipe describes how one or several products can be transformed into one or several products on a particular machine. Recipes can involve crushing, burning, hydration, milling, screening, grinding and blending. Some of those recipes start with one product and end with multiples. Others start with multiples and end with one. Recipes can involve a few of the final products. This might allow us to serve a customer with medium quality requirements by blending some high quality product and some low quality product if this might be needed.

An example of a recipe might be the screening of the run of kiln. The run of kiln is the lime at the exit of the kiln. This lime is a cluster of many different sizes of stones but of one homogenous quality. At the entrance of the sieve this lime agglomeration is sieved through a mesh. At the exit of the screening many different outcome products exit. Each product has a different size depending on the screening mesh that has been used.

Different recipes for a single machine can mean 3 things, either a machine can use different combinations of products to produce the same combination of products or a machine can use the same combination of products to produce different combinations of products or any scenario in between.

An example of a machine that can have multiple recipes is a kiln. We can decide to use smaller or bigger stones for example. As a result, at the exit of the kiln we will have different clusters of stones as well with very distinct size decompositions.

Once the limestones have been transformed through the different machines in to lime we can ship it to a distribution center and finally supply it to the customer.

2.20.3 Components of the supply chain in Malaysia.

The Lhoist's supply chain in Malaysia starts in a limestone mine in Tapah, Perak, Malaysia.

The limestone needs to be transported to the plants for the plants located on other sites. In Tapah, SPM and SPN there is a lot of inventory or storage space for raw limestone. Thus the raw materials can be stockpiled close to the kilns in all sites. The raw limestone doesn't suffer from storage but will reduce in size following every additional manipulation.

However once the limestone is burned into lime, the product cannot be stored as easily. This lime is reacting with CO_2 and is hydrophile. This product can then be further processed.

The lime is shipped to one of the 3 hydrator plants. Where it is subsequently hydrated. Lime is usually difficult to keep both in the production plant as in a downstream processing plant.

The majority of customers today are located relatively close around each respective plant. The export customers, who will be Tapah's main target, can leave from 2 ports in 2 modes. Either they leave in container in the biggest port of Malaysia or they leave in break bulk cargo in a smaller port.

As we look at the problem from a strategic point of view we won't consider the shipping timetables. Supply to the export customers will be assumed from Tapah because of the premium quality we have in Tapah.

2.20.4 Integrated model formulation.

The model we will describe in the following pages is multi-echelon. The number of echelons is defined by the number of subsequent machines that process the product and the distribution center. The model looks at variable costs in production for each machine and fixed costs for plants. No variable costs are considered in the warehouses, only fixed costs. The model restricts closing of plants if they have ever been opened i.e. an opening decision is thus permanent. The recipe model allow for divergent production processes. No inventory is allowed. All unused products are dumped at the end of each time period. Some operations are defined as being done by one machine even if in reality it would be several machines. An example is the extraction from the mine, this recipe has 0 inputs and is produced by such an agglomerated "machine". The transport cost is in function of the product being transported. We refer to subchapter 2.19 for the significant difference between different types of products' transportation price.

The set of indices is the following:

I : The set of customers

J : The set of warehouses

K : The set of plants

P : The number of products

S : The set of suppliers

T : The length of the horizon

B : The set of recipes/bills of materials

M : The set of machines

The parameters are the following:

R_in_{pbm} : The amount of product p consumed when running recipe b during one complete time period by machine m

R_out_{pbm} : Amount of product p created when running recipe b during one complete time period by machine m

D_{ipt} = External demand by customer i for product p in period t.

C_m = Capacity of machine m

Fk_k = Fixed plant cost

A_p = Dumping cost of product p

F_j = Fixed Warehouse cost

T_{jmp} = Transport costs of product p from machine m to warehouse j

T_{pij} = Transport costs of product p from warehouse j to customer i

$T_{pmm'}$ = Transport cost of product p from machine m to machine m'

V_m = Variable machine cost

V_s = Variable supply cost

The decision variables are the following:

p_{kt} = plant is open/closed {1,0}

w_{jt} = WH is open/closed {1,0}

x_{pmt} = Amount of product p, produced by machine m, in period t

s_{pmjt} = amount of product p, shipped from machine m, to warehouse j, in period t

$i_{pmm't}$ = amount of product p, shipped from machine m, to the next machine m', in the production process

m_{pjit} = amount of product p, shipped from warehouse j, to customer i, in time period t

b_{mbt} = Amount of time that recipe b is running during period t on machine m. $b \in \{0-1\}$

a_{pt} = Amount of product p dumped in period t

Problem P:

$$\begin{aligned}\text{Min z} = &\sum_{k,t} Fk_k p_{kt} + \sum_{t,p,s,r} V_s q_{rspt}, \forall p \subset P_s \\ &+ \sum_{b,m,t} V_m b_{mbt} + \sum_{j,t} F_j w_{jt} + \sum_{j,p,m,t} T_{jmp} s_{pmjt} \\ &+ \sum_{i,j,p,t} T_{pij} m_{pjit} + \sum_{p,m,m,t} T_{pmm} i_{pmmt} + \sum_{p,t} A_p a_{pt}\end{aligned}$$

The constraints:

Demand constraint:

$$\sum_j m_{pjit} w_{jt} \geq D_{ipt} \,, t \in T, p \in P, i \in C \tag{2.1}$$

Inbound Flow conservation:

$$x_{pmt-1} + \sum_{m'} i_{pm'mt-1} = \sum_b R\_in_{pbm} b_{mbt} + d_{ptb} \,, t \in T, p \in P, m \in M \tag{2.2}$$

Production and shipping flow conservation i.e. outbound Flow:

$$\sum_b R\_out_{pbm} b_{mbt} = x_{pmt} + \sum_j s_{pmjt} + \sum_{m'} i_{pmm't} \,, t \in T, p \in P, m \in M \tag{2.3}$$

DC flow conservation

$$\sum_{m} s_{pmjt-1} = \sum_{i} m_{pjit} \, , t \in T, p \in P, j \in J \tag{2.4}$$

An open plant or DC is open forever once opened.

$$\begin{aligned} p_{kt} &\geq p_{k,t-1} \, , t \in T, k \in K \\ w_{jt} &\geq w_{j,t-1} \, , t \in T, j \in J \end{aligned} \tag{2.5}$$

Machine capacity constraint

$$\sum_{b} b_{mbt} \leq 1 \, , t \in T, m \in M \tag{2.6}$$

Kiln capacity limitation:

$$\sum_{b} b_{mbt} \geq .75 \, , m \in \; M_{kilns} \, , t \in T, m \in M, k \in K \tag{2.7}$$

Link plants fixed cost to machines utilization.

$$p_{kt} \geq \sum_{t} b_{mbt} \, , m \in M_p \tag{2.8}$$

$$\begin{aligned} p_{k,t}, w_{j,t} \in \{0,1\} \, , k \in K, t \in T, j \in J \\ x_{pmt} = i_{pm'mt} = 0 \; \forall t = 0 \end{aligned} \tag{2.9}$$

The objective function minimizes the total cost of the supply chain. We minimize the fixed cost of running the plant and the variable cost of running the machines. We minimize the cost of supply. We minimize the fixed warehouse cost. We minimize the transport cost of any product from a machine to a warehouse, from a warehouse to a customer and between machines mutually. Finally we minimize the dumping cost in the last time period.

Constraint (1) represents the demand constraint. The delivered product from all open warehouses to a particular customer needs to meet at least his demand. For each customer and each product the sum of the shipments must be equal or greater than the demand.

Constraint (2) and (3) describe the flow conservation which must be respected for each product, machine and period. Decision variable b_{mbt} will define for how long each recipe is run and will allow us to match inbound flow consumed with outbound flow created. This is necessary because in some recipes there is mass loss in the form of CO2 or mass gain in the form of water.

Constraint (2) represents the inbound flow conservation constraint. The amount of product produced during the last period in a plant (i.e. the intermediate product.) and the amount of product supplied externally needs to be equal to the amount used by a machine. What is left will need to be dumped. Constraint (3) represents the outbound flow conservation constraint: For each product the amount of product produced or transformed by a machine needs to be equal to the intermediate products for the next time period and the products shipped to a plant m' from a plant m or the products shipped to a warehouse. Constraint (4) prevents plants and warehouses to balance between open and close. Once a plant/warehouse is opened it stays open forever. This constraint is because some overhead costs of opening/closing a plant/warehouse for the first time aren't modeled. Constraint (5) prevents any machine, no matter which recipes it is using, to produce more than it's capacity in one period. If we imagine $b = 1$ for a machine and a period this recipe can apply to, we use the full time capacity possible in one period on that particular machine. Because one machine can have multiple recipes, in this constraint we sum over the multiple recipes and make sure that less than the time capacity has been used. R_in and R_out have been defined according to the throughput it's possible to get in one time period and on one machine. Constraint (6) forces every kiln to operate at least at 75% of its capacity. Constraint (7) Forces every plant or warehouse that ships products out to be open. Constraint (8) opens plants and activates the fixed costs of a plant when any machine is operated in this plant.

2.20.5 What can be done differently?

The concept of a plant is only loosely defined in this model, instead the model uses machines whereas most authors would define plants more substantially. Constraint (8) forces plants to open. Transportation costs between machines in the same plant can in this model be either described as the real costs or be approximated as 0 because the inter machine intra plant transport can be seen as a fixed cost. One of the negative points of this is that it doesn't allow consolidation of shipments. As this is never the case today this is a safe assumption. This could be an interesting expansion.

The model used today by Lhoist doesn't model fixed costs. That's why they don't have any binary variables. No decision is being made to keep a plant or DC open or not.

Different scenarios are compared by "what if" scenarios where we force certain DC's or plants to stay open.

This model doesn't allow any inventory over time, what's more the model actively punishes unused products during each time period because they are considered as to be dumped.

We decided not to model any supply as in Lhoist Malaysia it's not done. This simplifies the reading of the model and would otherwise add one decision variable per product.

We modeled the dumping cost only dependent on product and not on location. If this model were to be used in a global setting we wouldn't want shipment of waste to dumping countries because dumping would be cheaper there. Dumping has been modeled after every time period. This can be deemed too strict in which case we can easily change the model to have a dumping period every X time periods or in the extreme case only at the end of the time horizon.

This model has no inventory. Each product can as a maximum be kept for one time period. Furthermore a product can only be passed to the next echelon be it a machine, a customer or a distribution center after a time period passed. Because this is a strategic model and if every period is defined as a small part of the time horizon this will not be a limitation to the model. Work in progress calculations based on x_pkt thus makes very little sense compared to the reality.

When running the model over a limited amount of time periods it will be important to initialize the model to some value so that there is not to much ramp up time.

We can restrict the recipe variable b_{ktmb} to binary. We chose not to do this because most machines aren't used all the time. And most machines switch recipes. Depending on the duration of one time period and the variety of customer demand the recipes will switch more or less often.

A similar dumping solution would be to have a dumping machine for each product and force all product that is left to go through this machine with a certain cost and a recipe resulting in no output. While this might be more elegant in notation it makes it more difficult to see which products are being dumped. Furthermore this allows us to easily extract the costs exclusive of the dumping costs. In case the dumping costs were virtual costs.

My experience here in Malaysia learns me that a lot of valid inequalities can be added based on real world constraints. For example as will be seen in the following chapters, the freight matrix that describes costs of shipping between all plants/DC's and customers has a lot of legs that were in fact infeasible. This was done by putting the freight rates at an unreasonably big amount.

2.20.6 Sources

This model was partly inspired by the model developed by Yu et al. in “Integration Location-Production-Distribution planning in a multi-products supply chain network design model” or by the second method Bredström et al. use to model the diverging flux in the pulp mill industry in their paper: “Supply chain optimization in the pulp mill industry—-IP models, column generation and novel constraint branches”. A broader analysis of those production-distribution models can be found in the literature review.

Bredström in a slightly similar model from 2003 has difficulties finding results over more than 70 time periods. 70 time periods represents periods of one month during 5 years. Today given the advances in technology over 12 years. It’s likely that today we will be able to diminish the lengths of those time periods, should we so wish.

The solution of this model can be facilitated by aggregating the time periods into longer time periods. A balance has to be stroked between shorter and more detailed time periods and solution time.

2.20.7 Applicability of the model

The developed model doesn’t allow stock keeping (nor intermediate nor final stock).

The model doesn’t make a difference between a facility that is already operational and a new facility. It doesn’t take into account the start up investment of a new facility. To make a balanced choice one should implement an initial investment cost of a facility.

This MIP model is thus not entirely appropriate to evaluate the impact of start-up Capex. Since the lime business is capital intensive, based on low value products, this Capex parameter is an important decision factor. For operational safety and security reasons in the production plants, a strict time constraint was imposed. This MIP model is thus considered as an inappropriate tool to establish a clear decision for reorganization or extension of the LMA existing operational network within the given time constraint. The MIP model would be better suited once a network is in place to decide which facilities should be used to deserve specific customers.

One of the crucial questions of this project being the design and eventual remodeling of the LMA operations. Implementing the MIP model would have been time intensive and a detailed development was considered by LMA as out of the scope and out of the allocated resources. As thus for the above mentioned reasons we stopped further development and fine tuning of the MIP model.

2.21 Excel model

In order to accelerate development of a more interactive and open model that was able to evaluate most of the gathered operational, commercial and logistical data we decided to develop an interactive model based on Excel. This Excel model needed to have the possibility to evaluate quickly different preset scenarios. The setback however is that automatic optimization between the different scenarios is not feasible. In other words every iteration needs to be implemented manually. For strategic and policy reasons LMA management pointed 3 preferential operation scenarios.

Due to the imposed time constraint we needed a model with an easy access and tuning capacity. Since a lot of the commercial data are based on estimation and projections for the coming years the model needed to permit fast evaluation of different data.

During development we were confronted with the injection of practical operational, commercial and logistic realities. The Excel model proved to be flexible enough for short term evolutions and reorientations. This flexibility however needs to cautioned by an excellent exchange between Corporate and LMA as steering this flexibility eliminates partly the objective theoretical evaluation. On the other side this flexibility allows for vertical integration of experience and strategy on one side and market and production feeling on the other side.

The Excel model allows to set a particular scenario in terms of production capacity and packing capacity for each potential plant. For each client and packaging pair, quicklime supply location, production location, packaging location and logistics terminal can then be allocated.

The model will automatically calculate the EBITDA of the scenarios. Based on this, discounted cash flows and a discounted cash flow comparison will be updated.

In the Excel model a scenario will be defined and will have to be optimized by hand. To make this feasible, small customers were aggregated. One might argue that we would have had to aggregate customers either way because, for example, it would have been impossible to get competitive logistic costs from all plants to all customers.

The Excel model has distinct tabs that define all costs. Therefore tabs describing the scenarios can be easily copied and varied endlessly without affecting the rest of the model and if costs change they can be changed for all scenarios at once.

Chapter 3

Case study

In this chapter we will describe in detail the application of the problem. The problem will be analyzed from a sales, a production and a distribution point of view. The centre of attention will be on the strategic implications.

All data are described in full. On request of Lhoist and in respect of the signed confidentiality agreement signed by all members of the jury. This chapter 3 is part of a special appendix not included in the present transcription. All members of the jury will receive the appendix in hard copy prior to the presentation.

Chapter 4

Conclusion and Criticism

4.1 Research conclusion compared to the literature

In this thesis we tried to give an overview of the production distribution literature that is applicable on the present project. We then develop a production distribution model that can be applied to the Lhoist supply chain problem. This model is different from what existed before because it models both the diverging flux and the multi-product aspect of the problem. We refer to chapter 2 for more critique and evaluation of the mentioned literature. With hindsight and based on the literature critiques it seems clear that the main difficulty is to have the most correct and precise data available. Since a lot of information is based on assumptions, previsions and projections, due to the nature of this data there is already an important margin of error. It becomes thus a target on itself to confront these data in order to reduce this potential deviation. The results of modelisation of a project are often limited by the extent and the robustness of the data injected. As we see by the sparsity of papers and cases about divergent supply chains in general and the popularity of good papers that exist, for example the paper by Arntzen et al (1995) there is still room for research in this area.

4.2 Critique on the practical realization of this study

4.2.1 Critique on the model

A closed model as described in paragraph 2.20 is more difficult to accept and to be thrusted by third parties. Model interaction for everyone concerned would have been very difficult. Thus fine-tuning and weighing of the different parameters, based on practical experience available, would have been difficult to use. Build trust and confidence through the project team with the executive managers in the power of the model takes some persuasion. For a third-party the literature may seem complex, furthermore it is relatively difficult to explain and gain the trust of managers about how exactly the model could be better than the intuition they have.

We refer to the critique in paragraph 2.20.7.

Using an excel file made the problem very accessible and interactive for everyone concerned. An excel model although it can become very bloated has the benefit that it is a familiar interface to anyone in a company. Third parties can easily change the data for one parameter and evaluate the impact on the global model. As long as we respect the raw data, this enables to evaluate the weight of each parameter.

Furthermore the model we developed made it visually very easy to change variables during meetings.

Having one master excel file where everything was linked proved to be a real plus, it means work can be shared instantly and every computer can handle the file. Furthermore anyone could be up and running in this file relatively fast. A user didn't need to understand everything from the file to be able to adapt things rapidly, except for debugging.

It took a long time to convince the management in Malaysia of the added value supply chain management could provide. Through this project that was realized in close collaboration with LMA, a better comprehension of possibilities is existing. It seems clear that the corporate supply chain team will be entrusted with other projects in the future.

Because we used an excel model where each scenario was predefined several scenarios that could have been viable and might have been a better solution could have been overlooked. For example the location of both new and old plants or distribution centers was never reconsidered. As highlighted by Venter and Dincer (1995) and as discussed in chapter 2. when management first identifies feasible configurations you can miss out on a lot of other possible solutions.

Off course flexibility and interactivity always supports a possibility of data orientation. All cost parameters were defined during the start up of the modelisation by the project team. In a theoretical world data don't change too much during the time the model is developed. There shouldn't be any feedback loop between the results and the data. By not fixing those data one can influence the scenario comparison significantly. On the other hand it was fortunate that cost data could easily be changed in one tab and have the results automatically update, first of all for the model simulation and furthermore, for the discounted cash flow comparison. Because in a situation where a companies takes over another one it takes some time for the particularities of the costs to transpire.

The model compares projection of discounted cash flows for the coming 15 years. I doubt the confidence of the sales team over the predicted sales numbers stretches that far. Fortunately the proposed solution has a direct pay back versus the reference scenario of a short period in the worst case sales scenario.

To explain the additional logistics cost proved to be a challenge and required a map of the clients that would show the distances between each client.

Decision makers will mostly tend to bridge their experience with the developed model on specific KPI's.

4.2.2 Impact of fuel prices

A big part of what makes export the big cash cow that it is in this analysis and therefore a big part of what validates the third scenario is relatively cheap transport. Hydrated lime has very low value per mass. Small changes in fuel in particular or in container rates in general will have a big impact on the margin for the exported lime. Today fuel rates are at a level that few people would have guessed a few years ago. Fortunately the trend seems to be set on low fuel prices. A disturbing movement is the course that 20 foot containers prices are taking. In most developed countries the inclination is to price all containers the same. The argument being that the biggest cost lays in the handling of the container. Because of the high density of lime and to a lesser degree of hydrated lime and consequently mainly the use of 20-foot (TEU) containers instead of 40-foot (FEU) containers (,most of the transport in the world is done in FEU). This trend could mean a doubling of the prices for all oceanic transport. Especially with Malaysia rapidly developing and labour costs rising.

Today in the Asia-Pacific region TEU are usually priced at 50% of their FEU cousins. The maximum difference of the rates LMA has compared to this benchmark of double the price is 10%. This is true even for destinations as Australia or Japan. Where the container handling is a significant portion of the cost.

Handling costs for different equipment sizes are rising and loading and discharging are becoming increasingly complex and time sensitive. The Transpacific Stabilisation Agreement (TSA) started recommending this year that rates for TEU's should be at 90% of the rates charged for FEU's as reported by the journal of commerce in May. The TSA is a discussion group of 15 of the largest ocean carriers in the eastbound pacific, i.e. in the trade routes between Asia and the US. As the transport cost is a significant percentage of the total cost to serve. (It can be up to 50% in LMA.) Of this transport cost an average of half the cost would be land transportation and the other half would be sea freight. A doubling of the sea freight would thus result in an increase by 25% of the cost to serve. This would significantly impact the LMA margin. This is a trend that might significantly diminish the advantage Lhoist has over the local suppliers in the export markets.

4.3 Further developments

Some questions remain and some points will deserve to be better analyzed in the future. We will describe 2 important points in the following paragraphs.

4.3.1 How will quality of the fuel usage in SPN impact on the decision?

There is a major quality difference between the lime from the multiple plants. For the validity of our results it is important to know whether lime from one plant can as easily be sold as lime from an other plant. If not this might greatly impact the decision to invest in one place instead of in another. We refer to the appendix in paragraph **??**.

Currently all finishing production processes are using lime from the Simpang Pulai plant. In the future when the plant in Tapah will be built, the finishing production processes will be using lime from the Tapah plant.

As we explained higher there is a major quality difference between lime produced in the different sites. Fuel can be upgraded in the site with the worst quality fuel that will result in an upgrade in the lime quality.

It remains to be seen if customers to whom Lhoist planned to sell high quality lime can be supplied from Simpang Pulai quality wise. Furthermore in the highlighted scenario there is an increase of global hydrated lime production. This means that we have a canibalisation of the projected lime sales by those new sales sales. Unfortunately this will again impact on the good quality lime quantity available.

The shift of secondary final product from Simpang Pulai to Tapah will significantly change available final products in both qualities. In Tapah we will have less premium grade and in Simpang Pulai we have a surplus of second grade. This situation will need to be addressed commercially with one modulating factor, the choice of fuel quality in Simpang Pulai with an embedded price variation.

4.3.2 Can we locate the logistics terminal somewhere else?

We started from a discreet number of locations where plant or terminals could be located. While this makes sense for plants as there are significant overhead costs that can be shared it makes less sense for logistic terminals.

Especially in one of the locations the lease will expire in 2019, it might thus be more careful to build a logistics terminal somewhere else.

In other locations the urgency is different and it might be strategically interesting to keep the same location as it gives the options to be flexible in case of a surge in demand. Maintaining the production tools in place with a minimum maintenance for a certain period of time would give a possibility of restarting with a minimum investment.

4.4 Conclusion

The Lhoist Malaysia supply chain network is facing severe issues in terms of safety, reliability, quality of the products and ecology for some of it's installations. Those installations must be either upgraded or replaced.

3 scenarios were compared with the current setting:

- Closing of a plant and the upgrading of 2 others
- Construction of a new facility with a limited capacity
- Construction of a new facility with an important capacity ...

Based on available information, projections by commercial departments and priorities set by LMA, we recommend Lhoist Malaysia to build a new production facility of an important capacity, to close the formerly discussed plants and keep a logistic terminal in all former plants.

This solution will have a better return on investment in a pessimistic sales scenario and has a lot more potential upside in an optimistic sales scenario.

The rationale are:

1. Operational expenditure savings: The lower cost of production both in fixed and variable costs is slightly counterbalanced by higher distribution costs still the opex savings are significant.
2. Capex optimization: The Capex of new facility compared with the Capex required to upgrade the old facilities to Lhoist standards is not considerably larger and will rapidly be compensated by the decrease in costs.
3. The total capacity will increase: the envisioned production potential will be higher than the current capacity, and will give room for growth and export markets.

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