CRANFIELD UNIVERSITY

CRANFIELD SCHOOL OF MANAGEMENT

CRANFIELD CENTRE FOR LOGISTICS & SUPPLY CHAIN MANAGEMENT

MSc THESIS

Academic Year 2002-2003

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Optimisation of a European Bulk Delivery Network of a chemical company based in the UK

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August 2003

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science

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Στον αγαπημένο Ανδρέα Πατρώνη

Το ξέρω πως μας προσέχεις και μας χαμογελάς απο εκεί πάνω,

Μακάρι να με έβλεπες τώρα παππού!!

Γιάννης ...

Acknowledgements

The first people I would like to thank from the depths of my heart are my family, without their support, love and help these 5 years would have been much more difficult and long.

Ευχαριστώ Μαιρούλα, Κώστα, Τζωρτζίνα και Ανδρέα

Especially for this piece of work, I would like to express my respect and gratitude to Alan Smart whose support and attitude made this task easier.
I would also like to thank all of the Huntsman Tioxide staff who patiently answered all of my questions, but special thanks go to Paul Hodgson, Dave Pearce and Jacqui Wilford for all their help.

Special thanks go to two very special people in my life,

Μικαέλα Σκουλά
and
Γεώργιος Ζορμπάς

, for their support during the tough times

Abstract

This thesis is concerned with the Optimisation of the European Bulk Delivery Network of a large chemical company based in the UK. The company supplies a large percentage of T_iO_2 in large dry bulk tankers across Europe. Due to the high cost associated with this form of transport, packed pigment is transported to remote filling stations (FS), were tankers are filled and tanker journeys are short.

The prime objective of this thesis is to find the optimum locations for filling stations throughout the European continent, and the secondary objective of this thesis is to reduce the cost of the European Bulk delivery operations.

A mathematical model was used to locate the optimum locations for these FS. From these optimum locations a feasible scenario was constructed and proposed.

With this proposed scenario there is a significant reduction in tanker travel distances as well as a significant reduction in the overall cost of serving European customers in bulk.

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1 Chapter 1 – Introduction

1.1 Introduction

This thesis is the document produced after an investigation done by the author for a large chemical company, hereafter referred to as the Company. This chapter is concerned with presenting a brief Company background and establishing the terms of reference of this research as well as its objectives. In the following chapters an investigation on the literature on depot location problems has been attempted and a methodology to approach the problem has been selected. In the last chapters of this thesis the findings of the research are going to be presented as well as a proposed solution based on these findings. In the concluding chapters, the proposed solution is going to be compared to the optimum solution and a critique of the work done will be attempted.

1.2 The Company

The Company is, as aforementioned, a chemical company based n the UK, part of very large multinational group of companies. The Company produces Titanium Dioxide (TiO_2) pigment used in very many applications, from the food industry to the paint industry. There are 5 manufacturing plants throughout Europe, 2 in the UK, in Grimsby and in Greatham, one in Spain (Huelva), Italy (Scarlino) and one in France (Calais). Their customer network is spread throughout Europe with most of their customers being in the central European area. There are also a total of 8 filling stations throughout Europe. Filling stations exist on the Grimsby, Greatham and

Calais manufacturing sites as well as in Santander (Spain), Grosseto (Italy), Wesel (Germany), Turku (Finland) and Gothenburg (Denmark).

The Company has rationalised their manufacturing plants and now have each manufacturing plant dedicated to 2-3 grades of TiO_2. The Company produces 14 grades of TiO_2 of which 10 are sold in bulk. The following table shows the different grades produced in the different manufacturing plants.

The Company provides the TiO_2 pigment to its customers either packed or in bulk. The unit load for packed goods is one tonne – this could be twenty 25 Kg bags on a pallet which equates to 1 tonne or in one tonne big bags (Tiotainers) on a pallet. In the case of delivery in bulk the pigment is delivered in belly tankers.

Plant	Grade	Quality[1]	Plant	Grade	Quality
Greatham	R-TC 90	PR	Calais	TR 92	PR
		ST			ST
	TR 81	PR			SS
		ST		TR 85	PR
	R-TC 30	PR			ST
		ST		C 300	PR
					ST
Grimsby	FC 5	PR	Scarlino	XL	PR
		ST			ST
	HD 2	PR		TR 92	PR
		ST	Huelva	TR 28	PR
	TR 92	ST			ST
				FC 5	PR
					ST

Table 1.1, Grades Produced on Different Sites

The volume of sales of the Company in the year 2002 was in the region of 115 thousand tonnes and this figure is expected to rise in the year 2004.

[1] The quality of the grades is PR (Premium), ST (Standard) and SS (Sub-standard)

1.3 The Company's Operations

This thesis is concerned only with the Bulk Delivery Network of the Company and as such only the operations of the company relating to the Bulk Delivery Network will be discussed.

The company manufactures a grade of pigment at a particular manufacturing site. If the order is from a customer that is close by the manufacturing site then the pigment is loaded into tankers – if this is possible – and the pigment is delivered to the customer. In the case of the customer being a great distance from the manufacturing site the pigment is packed and then transported to the corresponding filling station.

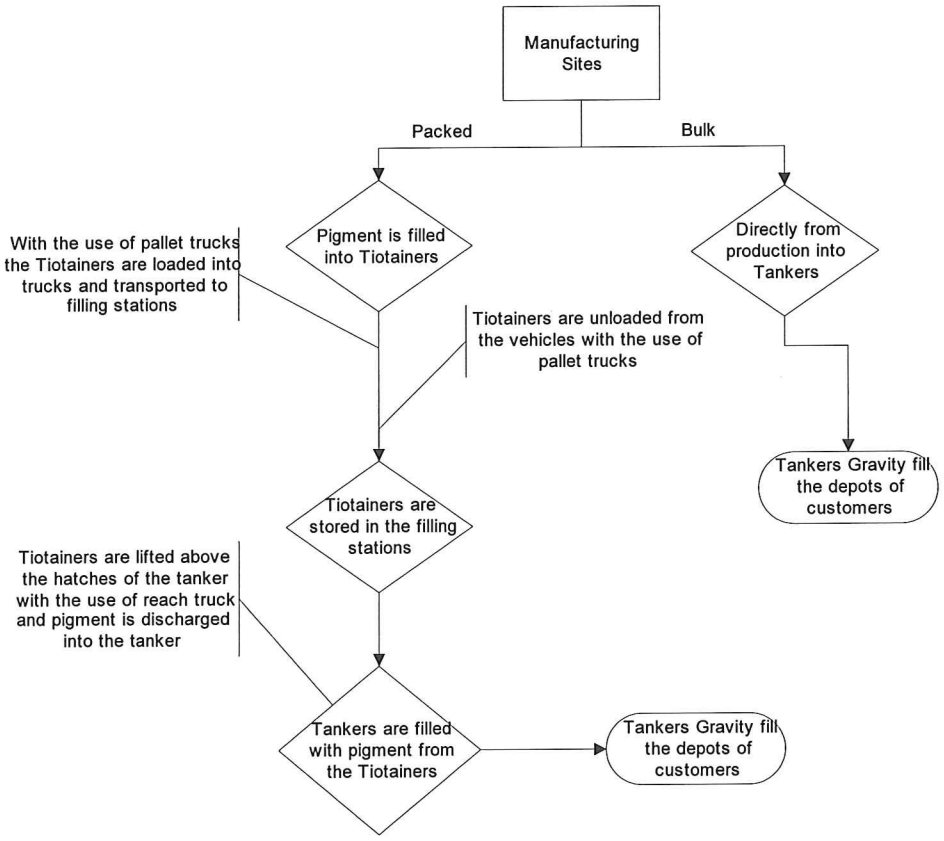


Figure 1.1, Flowchart indicating how the pigment is moved and handled between manufacturing sites, filling stations and customers.

These filling stations act as depots and have the facilities to fill tankers from the packed goods. At the filling stations tankers are gravity filled and despatched to the customer. Figure 1.1 above clearly illustrates how the pigment is moved and handled between the manufacturing sites, filling stations and customers.

1.4 The Problem

Delivering bulk to customers, either directly from the factory or via a filling station requires additional equipment and a more complicated delivery network.
The more complicated delivery network is due to the requirement for filling stations. In most cases the Company has chosen to deliver in tankers that will be exclusively used for the company's grades of titanium dioxide. Unlike tankers, which can be used to transport a wide variety of items, the company's tankers have no return journey when delivering to any of the customers. Therefore the longer the journey from the filling point to the discharge point, the higher the cost differential between bulk and packed deliveries. This has become worse since the alignment project was put into place. Whereas previously, grades were made at several factories and the journeys were shorter, alignment has resulted in the customer, in some cases, being much further away than the factory that produces their grade. By installing a filling station close to the customer, the additional cost of double handling is offset by the shorter journey made by the tanker.

1.5 Objectives and Terms of Reference

Having looked at some of the problems of the company, this thesis is going to be concerned with the location and the number of the filling stations in order to reduce the cost of serving customers in bulk. Thus there are two objectives to this thesis;

- the primary objective of this project is to find the optimum locations for filling stations throughout the European continent.

This will be done by analysing the Company's current European Bulk Delivery Network operations and proposing the optimum locations for filling stations.

- The second objective of this project is to reduce the cost of the European Bulk Delivery operations.

The cost of any Delivery Network can be reduced in many ways. The whole of the supply chain can be taken into account and a holistic view of the company's operations can be made. Following the terms of reference that were agreed between the author and the Company, this thesis is concerned only with finding the optimum number and locations of filling stations in order to reduce the tanker travelling, which is the most costly operation of the delivery network. In addition to the above, it was agreed in the terms of reference that this project would not take into account any inventory holding costs within the European Bulk delivery network. It was clearly stated to us by the Company that this thesis was part of a wider project that was taking place. In this wider project the inventory holding issue was taken into account, and as such this thesis would not be concerned with it.

2 Chapter 2 – Literature Review

In this chapter the literature concerning the association between the warehousing costs the inventory holding costs and the transport costs in a distribution system is reviewed. It will be demonstrated that a trade-off between these two costs has to be made in order to find an optimum solution. This trade off will be more clearly illustrated in Chapters 5 and 6 were the analysis is shown. Also the literature concerning the different approaches to the depot location problem is going to be reviewed. It is going to be illustrated that there are mainly two approaches suggested by the literature and the use of each of them depends on the various parameters of the problem in hand.

2.1 Total Cost Theory

The total cost of a distribution system is dependant on many factors. The total distribution cost can be broken down to three categories. These are the warehousing costs, inventory holding costs and the transport costs. In the following paragraphs of this chapter, these costs will be analysed and their importance and how these affect the total cost of a distribution system will be presented. It will be seen that these costs are interdependent with each other and that each of the cost parameters described hereafter will vary in different and conflicting ways.

2.1.1 Warehousing Costs

Warehousing costs can be broken down into 5 categories as Rushton et al (2002) illustrates. These are:

	%
❖ Building costs (rent, rates, depreciation)	24
❖ Building services (heating, lighting, etc)	16
❖ Equipment (rental, leasing, maintenance)	13
❖ Labour (direct)	38
❖ Management and supervision	9

The average cost relationship between these categories has been included in the above list, but it must be stressed that these relationships will vary under different circumstances such as industry, product type, volume throughput etc.

These warehousing costs however will vary in relation to the other distribution costs and have diverse effects on the cost relationship with the other distribution costs. This diversity could be due to the depot size, location and the number of depots in the distribution system.

Firstly the effects of the total annual volume throughput of the depot and consecutively the depot size will be discussed. As Willis (1977), Rushton et al (2002) and others state, there is a fixed cost and a variable cost associated when running a warehouse. The fixed cost will mostly depend on the building costs which vary with the location of the depot. The variable cost will depend on the annual tonnage throughput. As the annual volume through the depot increases so will the amount of handling equipment and manpower will increase in order to ensure that the depot runs smoothly and efficient.

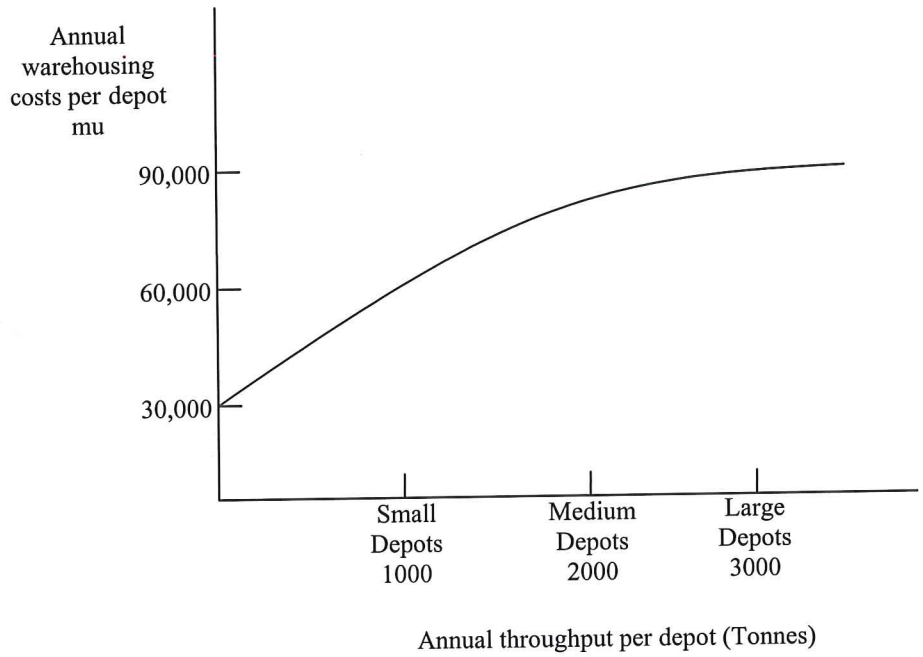


Figure 2.1 Warehousing costs showing economies of scale – adapted form Willis (1977) pp 146

It would have been expected that the cost per tonne for each additional unit of throughput would remain constant. Although in practice as Willis (1977) suggests, economies of scale come into effect and the cost per tonne tend to be higher at small depots than at large ones and the variation of warehouse costs tend to be like in figure 2.1 above. It must be noted though, as Rushton (2002) suggests that eventually diseconomies of scale could occur since very large depots can be adversely affected by such conditions as excessive internal distances, problems of management etc.

The effect that the number of depots in a distribution system has in the total costs of the system can be also explained by the economies of scale argument, as Rushton (2002) explains. The change in a distribution system is likely to be from a large depot to two smaller ones. This change will not incur double the costs because the change is to two smaller depots rather than two large depots. The costs will almost certainly increase though since there will be a need for more stock, more storage space, more management etc. Care must be taken over a generalisation of this nature. As Rushton

(2002) suggests, the cost structure of each depot could vary depending on many practical reasons. Some of these may include high or low rent according to the location of the depot or high or low labour rates.

2.1.2 Transport Costs

The transport costs of every distribution system can be divided into the delivery costs and the trunking costs. These two costs are adversely affected by the location and the number of the depots in the system.

Delivery transport is the delivery of goods from the depot to the customers. The cost of this form of transport depends heavily on the mileage travelled by the fleet of the delivery vehicles. This mileage, as Rushton (2002) states, is comprised of two parts; the 'drop' mileage and the 'stem' mileage. The 'drop' mileage is the mileage travelled once a delivery zone has been reached and the 'stem' mileage is the mileage travelled to reach the drop zone. The 'drop' mileage doesn't change regardless of the number of the depots, but the 'stem' mileage is proportional to the number of depots in the system. Figure 2.2 illustrates this point graphically.

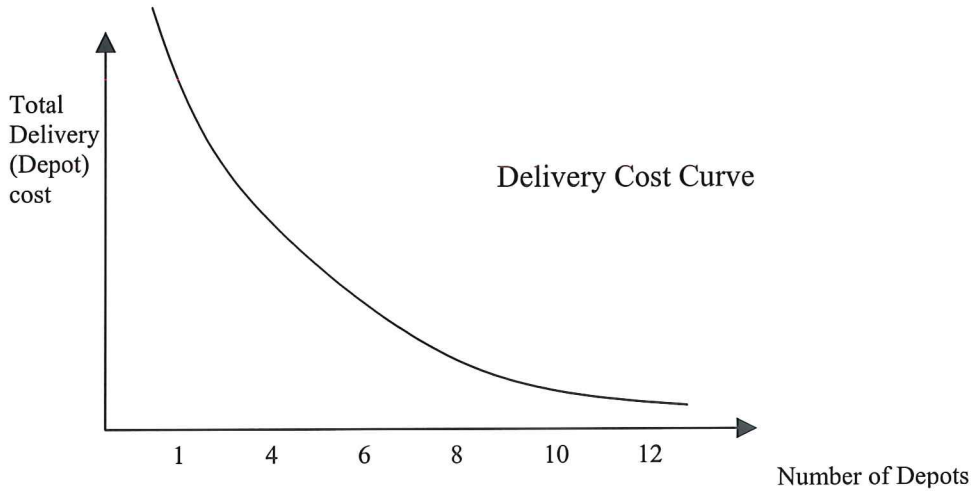


Figure 2.2, Relationship between No of Depots and Total delivery costs – adapted from Ruston (2002) pp119

Trunking or primary transport is the transport of goods – generally in bulk or palletised – from the point of production or central finished goods warehouse to the depots. As with delivery transport, this form of transport is affected by the number of depots in the system. As the number of the depots in the system is increased the cost of the primary transport is also increased but not at the same degree as with the delivery transport, as Rushton (2002) suggests. The effect of the number of depots on the cost is greater when there is a smaller number of depots. Figure 2.3 illustrates this relation graphically.

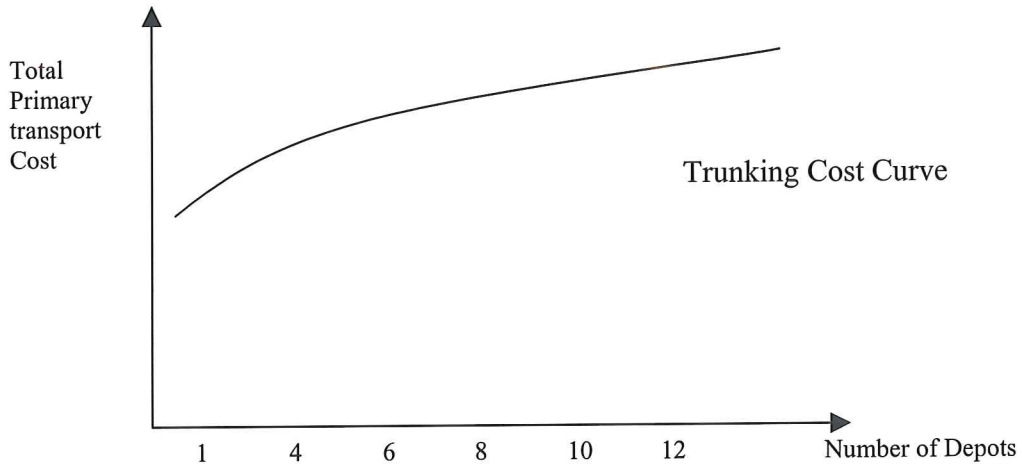


Figure 2.3, Trunking costs (total primary transport costs) in relation to the No of depots – adapted from Rushton (2002) pp119

When the delivery cost and the trunking cost are combined it is regarded as the total transport cost. This total transport cost will reduce the greater the number of depots in the system. Figure 2.4 illustrates this point.

Another important cost that has to be included is the cost of holding inventory. The cost of holding inventory is comprised of several costs, as Rushton (2002) suggests and those are

- Capital cost (the cost of physical stock)
- Service cost (stock management, insurance)
- Storage cost (considered earlier in the warehouse cost)
- Risk costs (shrinkage, deterioration of stock etc)

These costs when taken together and measured against the total number of depots can be represented as shown in figure 2.5.

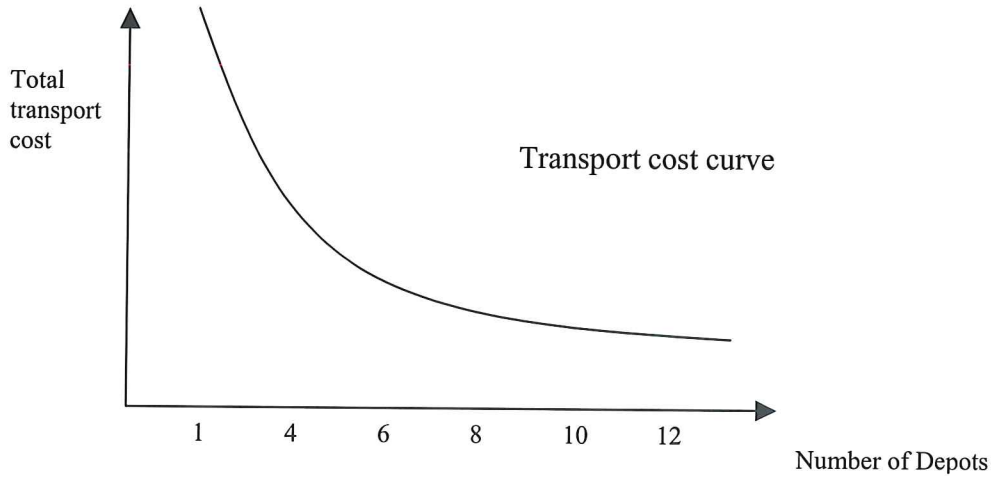


Figure 2.4, Total transport costs in relation to the No of depots – adapted from Ruston (2002) pp120

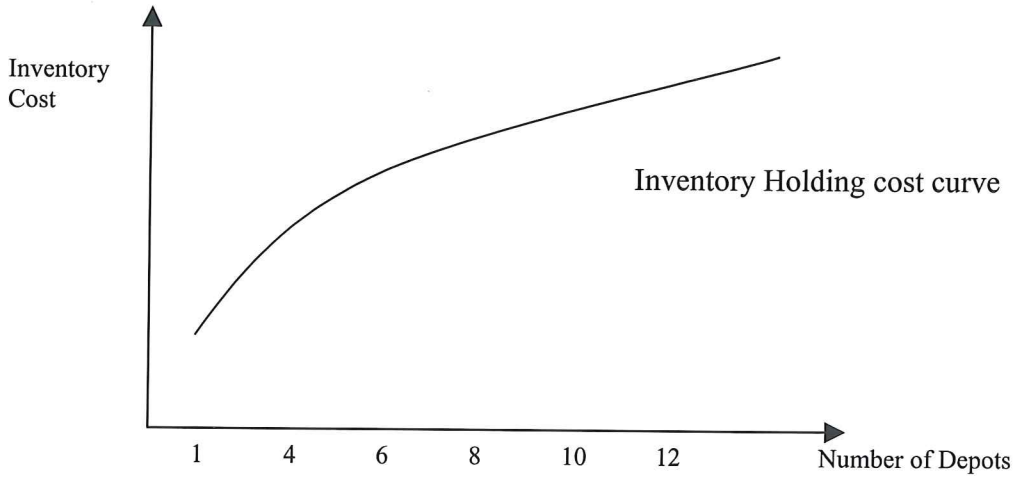


Figure 2.5 Inventory holding costs in relation to the No of depots – adapted from Rushton (2002) pp121

2.1.3 Total Cost Function

From the previous paragraphs a cost function for the total distribution cost of a system can be derived. As the literature suggests the global cost function C is given by:

$$C = T_1 + T_2 + FW + VW + I + S \quad (1.1)$$

where:
- T_1 is the trunking cost
- T_2 is the delivery cost
- FW is the fixed warehouse cost
- VW is the variable warehouse cost
- I is the inventory holding cost, and
- S is the cost of lost sales

As mentioned in the introductory paragraph, as the number of the depots in the system increase, these factors vary in different and conflicting ways, as Willis (1977) suggests. Willis (1977) continues by stating that T_2 and S will decrease (not necessarily in a linear fashion) and T_1, FW and VW will increase. A total cost curve can be drawn as shown in figure 2.6 with a minimum point obtained through the balancing of these two sets of conflicting costs. It must be clarified that in graph 2.6 the line marked T_1+T_2 is the sum of these two costs and that this sum follows the trend shown not the individual costs.

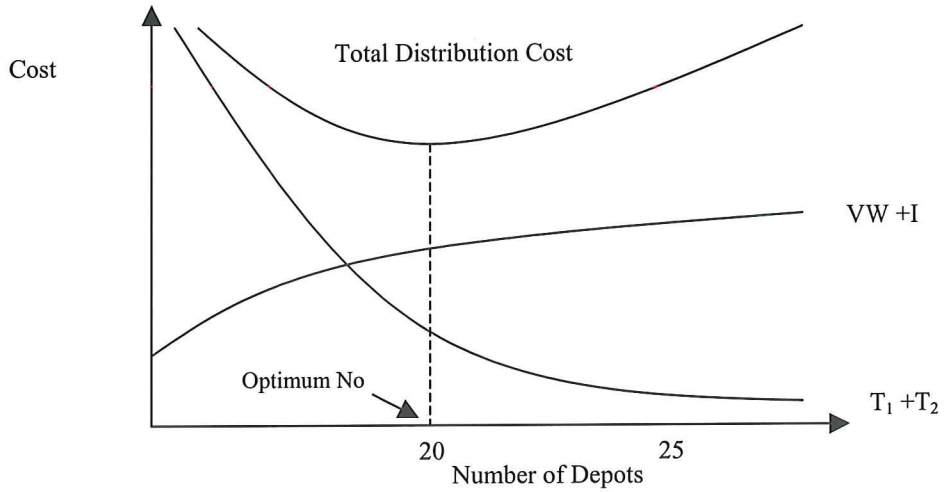


Figure 2.6, Total Cost Curve – adapted from Willis (1977) pp145

2.2 Methods of Approach to Depot Location

The site selection problem is by no means a single problem to which a single solution can be found. In order to find the optimum site or location for a depot there is a combination of interrelated problems that must be solved, of which four can be identified, as Watson – Gandy (1969) suggests.

1. Determine the number of depots
2. Determine the location of sites for these depots
3. Determine the allocation of customers to these depots
4. Determine the size of the depot for each site, taking particular account of the economies of scale inherent in the operating costs of such centres.

Following the suggestions of Watson – Gandy, it is evident that the general approach to the depot location problem is to tackle each of these problems in turn assuming that the all the other parameters remain constant. Although this approach seams to follow some logical steps, the interrelations of these problems can prove to be very complex and as such it has often been found necessary to simplify the structure of the model

and to employ heuristic procedures for finding solutions to these problems, as Eilon et al. (1976) suggests.

There are two general approaches suggested in the literature for the site selection problem. The first approach suggests that the site can be situated anywhere in the area under consideration; there is an infinite number of possible locations for sites. The second approach suggests that there are only a finite number of possible sites in the area that is of interest, that is, there are only a few possible sites that are feasible. The first approach is the infinite set approach and the second is the feasible set approach, and these two approaches will be discussed in the following paragraphs.

2.2.1 The Infinite Set Approach

The Infinite Set Approach is the oldest approach form the two that will be considered in this discussion starting with the work of Weber (1929). The corner stone of this approach is that it assumes that the transport cost is a monotonic function of distance and that this function can be minimised by minimizing the sum of the weighted straight line distances, Eilon (1971).

As aforementioned the infinite set approach does not require that the locations which are selected are *a priori* attractive. This means that when presented with the problem of locating a site for a depot, all of the area under consideration is considered to be a possible site for that depot. This could yield some problems as Eilon (1971) suggests. The sites elected by the model could involve non-feasible locations, like for example a mountain range.

2.2.2 The Feasible Set Approach

The feasible set approach has been constructed by considering the infinite set approach and addressing its limitations. The first limitation addressed, as Eilon (1971) suggests, is the fact that in general transportation costs do not vary linearly

with distance. The second limitation that the feasible set addresses is that the operational costs of the depots can vary considerably from town to town within a country, or even from location to location within a city. Eilon (1971) continues by stating that the approach implicit in the feasible set method is to select a number of sites which are known to be available and for which the actual operational costs and the actual costs of transportation to each customer can be determined.

2.3 Single Depot Location for Deterministic Demand

In most cases, as Eilon (1971) suggests, there is no need to take into account the whole distribution system of a company but only parts of it. A distribution system can be broken down in order to determine the location of a distribution depot in a single depot system or a sub system.

2.3.1 The Model

Eilon (1971) suggests the general model used in order to determine the optimum location for a single depot system is going to be described in the following paragraphs. As it is a single depot system the model consists of a single depot, whose location in Cartesian coordinates is described by (x_0, y_0). This depot will supply n customers, whose locations are known and denoted by (x_j, y_j) where $(j = 1,2,3,...,n)$. If the cost of transporting goods to customer j from the depot is denoted c_j, then the total local distribution cost will be:

$$H = \sum_{j=1}^{n} c_j \qquad (2.1)$$

If the values of c for each customer are known then using the feasible set approach the cost could be found by just solving equation (2.1). If the case is that the cost of transporting goods to the customer is linearly proportional to the weight or amount transported and the distance transported then the cost function will be,

$$c_j = \alpha_{0j} w_j d_j \tag{2.2}$$

where α_{0j} = cost per unit weight (or amount) and per unit distance from the depot to customer j;

w_j = weight (or amount) transported to customer j from the depot, from now on referred to as the customer weight;

d_j = the distance from the depot to customer j.

As the distance we consider the straight-line distance (also called the *radial distance*), and this can be found from:

$$d_j = \left[(x_0 - x_j)^2 + (y_0 - y_j)^2\right]^{1/2} \tag{2.3}$$

in the case where α_{0j} depends only on the customer being served and not on the location of the depot the cost function comes to:

$$c_j = \alpha_j w_j d_j \tag{2.4}$$

resulting in the cost function

$$H = \sum_{j=1}^{n} \alpha_j w_j d_j \tag{2.5}$$

As, Brink and de Cani (1957) suggest, the cost function of this model can be any continuous function. It could be proportional to the log of the distance to the customer or the speed of delivery. But Brink and de Cani emphasise that any suitable function can be used in a particular case, subject to the condition that the function is continuous.

2.3.2 Centre of Gravity Method

The centre of gravity method is generally used to find the initial depot location for a cluster of customers were there is no possible or feasible location known. As Willis (1977) states, the use of this method generally gives a close approximation to the true optimal depot location, particularly if the discrepancy between the weighting of the consuming centres is not great. The coordinates of the centre of gravity are found by:

$$x_0 = \frac{\sum_{j=1}^{n} w_j x_j}{\sum_{j=1}^{n} w_j} \quad \text{and} \quad y_0 = \frac{\sum_{j=1}^{n} w_j y_j}{\sum_{j=1}^{n} w_j} \qquad (2.6,7)$$

It must be noted at this point that the notation used in all of the expressions and formulae will be consistent and follow the explanations given in paragraph 2.3.1 of this chapter.

An alternative method that has been used is to employ a weighted centre of gravity method, for example, of weighted by the costs of transporting goods to customer j ,as Mossman and Morton (1965) suggest. This alternative attempts to take into account the possible differences in transport rates between different customers. The centre of gravity in this alternative is given by:

$$x_0' = \frac{\sum_{j=1}^{n} \eta_j w_j x_j}{\sum_{j=1}^{n} \eta_j w_j} \quad \text{and} \quad y_0' = \frac{\sum_{j=1}^{n} \eta_j w_j y_j}{\sum_{j=1}^{n} \eta_j w_j} \qquad (2.8,9)$$

where η_j = the cost per unit weight (or amount)

2.3.3 Mechanical Analogue Method

The Mechanical analogue method is the so-called strings and weights method of solving the depot location problem. This method, illustrated in figure 2.7, is a very simple but effective method with a strong visual impact as Shea (1966) says in his paper. A map is pasted onto a table and holes are drilled at the locations of the customers, and/or the factories. Strings are then passed through these holes with one end carrying a weight proportional to w_j $(j = 1,2,3,...,n)$, and the other end of the string tied together with the other strings on a washer or ring.

The ring is pulled to one side of the map and then the system is allowed to balance by the effects of the weights on the strings – which represent the customer demand. The point were the ring is in an equilibrium is the point on the map of the optimum location for a depot.

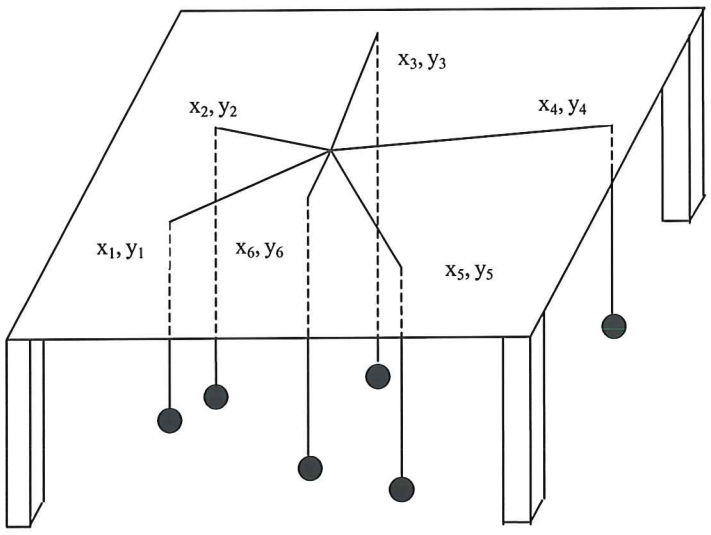


Figure 2.7, The Mechanical Analogue

2.3.4 The Numeric-Analytic Method

The numeric-analytic method was first suggested by Miehle (1958) and is the numeric equivalent to the mechanical analogue. The objective of the depot location problem is to minimise the cost. This cost is expressed by the cost function (2.5), and as such by minimising equation (2.5) the minimum cost will be found. Equation (2.5) can be minimised by taking partial differentials with respect to the depot coordinates (x_0, y_0) and setting these to zero:

$$\frac{\partial H}{\partial x_0} = \sum_{j=1}^{n} \alpha_j w_j (x_0 - x_j) \Big/ d_j = 0$$

and, (2.10,11)

$$\frac{\partial H}{\partial y_0} = \sum_{j=1}^{n} \alpha_j w_j (y_0 - y_j) \Big/ d_j = 0$$

These equations can be solved with respect to x_0 and y_0, and from the initial estimated location the following optimizing solution can be found:

$$x_0'' = \frac{\sum_{j=1}^{n} \frac{\alpha_j w_j x_j}{d_j}}{\sum_{j=1}^{n} \frac{\alpha_j w_j}{d_j}} \tag{2.12}$$

and,

$$y_0'' = \frac{\sum_{j=1}^{n} \frac{\alpha_j w_j y_j}{d_j}}{\sum_{j=1}^{n} \frac{\alpha_j w_j}{d_j}} \tag{2.13}$$

By using these improved values (x'', y''), the distances to each customer d_j are recalculated and the model proceeds iteratively until no improvement can be made.

2.4 Conclusions

From the literature review on the total distribution costs and their relation with each other, as well as the review on the methods of approaching the depot location problem, some conclusions must be drawn concerning the findings. It was seen that the total distribution costs can be divided into the warehousing and the transportation costs. These two elements of the total distribution costs are closely related and by changing one aspect of the network – say locations of warehouses – all of the elements of the total distribution cost are affected.

From the review on the literature of the methods to approach the depot location problem the following conclusions can be made. There are two approaches suggested by the literature; the infinite set approach and the feasible set approach. The infinite set approach was the first to appear and assumed a linear relationship between the straight-line distance between the customer and the depot and the cost of delivery. The feasible set approach addressed certain limitations of the infinite set approach and the basic difference is that this approach requires predetermined sites that are feasible and all the costs associated with these are known and a selection between these sites can be made minimizing the cost function.

Different mathematical techniques were also reviewed in this chapter. They are used in these approaches to eventually derive the optimum solution. With the explanation of these techniques, a more sound and logical understanding of the way the approaches work, is achieved.

Using the knowledge acquired from the review on the literature on these topics, the methodologies used in this thesis were chosen. In the next chapter the available existing methodologies are going to be presented. From these available methodologies, some were selected to be used while undertaking this project. The selected methodologies are going to be presented and the reasons for their selection are going to be explained.

3 Chapter 3 – Methodology

3.1 Introduction

From the literature review it was seen that there are two approaches to solve the problem of depot location; the infinite approach and the feasible approach. In this chapter the methods used to reach conclusions throughout the different stages of the analysis are going to be presented as well as the reasons for their selection.
In the initial paragraphs of this chapter a separate literature review will be presented in order to clarify some of the methods that are going to be used. This discussion will be in reference to different qualitative and quantitative methods that will be used in this project.

3.2 Qualitative and Quantitative Methods

In this paragraph a representative brief list of Qualitative and Quantitative methods of research is going to be presented. Before presenting the various methods though, the meaning of these two kinds of methods must be explained.
Van Maanen (1983) defines qualitative techniques as an 'array of interpretative techniques which seek to describe, decode, translate and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world'. Easterby-Smith (2002) states: quantitative techniques are those in which the process of data collection and the process of data analysis are two distinct activities. Explaining the definition of Van Maanen, qualitative techniques are those used to interpret phenomena and not to analyse them quantitatively but generate insights about how people view the world around them.

The most widespread qualitative technique is the interview. There are many forms of interview that vary depending on the objectives of the interviewer. There could be

hundreds or thousands of interviewees in order for the researcher to understand what a sample of the population's beliefs are in relation to a particular matter or situation. Another form of interviews is when the researcher's objective is to develop an understanding of the respondent's 'world' so that the researcher might influence it, either independently or collaboratively as in the case of action research like Easterby-Smith (2002) suggests.

As aforementioned quantitative methods are those were one can distinctly identify a data collection process and a data analysis process. Methods that use mathematical tools, like descriptive statistics, to analyse data gathered by means of questionnaires.

In this thesis a mix of quantitative and qualitative methods were used to gather and analyse the data and reach a final conclusion. As Abrahamson (1983) points out, this approach prevents the research to becoming method bound: the strength of almost every measure is flawed in some way or other, and therefore research designs and strategies can be offset by counter-balancing strengths from on to another.

3.3 Available Methods

In this paragraph the three available methods for solving the depot location problem will be presented.
There are mainly three different types of methods that are available, to solve the depot location problem; these being by means of a mathematical modelling, by means of a simulation and by means of heuristics.

Mathematical modelling is a process that translates observed or desired phenomena into mathematical expressions. There are various ways to classify mathematical models, as Lawrence and Pasternack (2001) suggest. One way of classifying them is by the purpose of the model. Optimisation models seek to maximize a quantity or minimize a quantity that may be restricted by a set of constraints. Prediction models,

as Lawrence and Pasternack (2001) continue, have the function of describing or predicting events. These models are almost always part of larger optimisation models. Another way of classifying mathematical models is by the degree of certainty of the data in the model. Using this criterion to classify mathematical models there can be Deterministic models and Probabilistic (Stochastic) models. The deterministic models assume that the data inserted into the model are known with certainty, whereas in the probabilistic models one or more of the input parameters' values are determined by probability distributions, as Lawrence and Pasternack (2001) state.

A simulation, as Lawrence and Pasternack (2001) state, develops a model to evaluate a system numerically over some time period of interest. Its purpose is to estimate characteristics for the system, which can then be used to select the best policy from a set of alternatives under consideration. Unlike many analytical techniques, they continue, a simulation does not rely on an algorithm to solve for the optimal solution; instead, a computer program known as a simulator is used to evaluate each option. There are generally two types of simulations; continuous and discrete simulations. Continuous simulations are those in which the state of the system changes continuously with time and discrete simulations are those in which the model monitors changes that occur at discrete points in time.

Heuristics are algorithms used in solving combinatorial optimisation problems. They aim to reduce the computational time requirements of solving combinatorial optimisation problems by searching efficiently specific areas of the solution space.

3.4 Method Selection

From the above array of methods available for use, a mathematical model was selected to optimise the European bulk delivery network of the company. The reasons for this selection are described in the rest of this paragraph.

After reviewing the problem and the objectives of this research it was determined that a mathematical model would suffice to yield an optimum solution for the problem in hand. Since the whole of the data provided by the company was in spreadsheet format it was logical that the solution method would follow this format. That meant that the company could use the mathematical model in the future without the requirements of any other software or capital expenditure.

The use of a simulation model would require complex and costly simulation software that was not at the researchers' disposal. Another reason why the simulation model was not selected was because of the time constraints of the thesis.

The heuristics method was not selected because the problem in hand did not require the use of such methods, since the mathematical model was more than capable of providing an optimum solution.

3.5 Methods Used

In the following paragraphs, the methods used in the various stages of the analysis of this thesis are going to be presented. The paragraphs are divided into the three main areas of the analysis undertaken in this thesis. Firstly, a brief overview of the methodology is going to be presented before the steps are expanded in the following paragraphs.

Firstly the base case must be established. The location of the current filling stations, the customer network and the demand of each customer must be known. A very important factor of the base case is also the origin of each grade of pigment that each customer wants. After all of this information is collected the costing of the base case must be done. As it is going to be seen in chapter 4, there are three elements of cost associated with the bulk delivery, trunking cost, handling costs at the filling stations and the tanker cost from the filling station to the customer. After the base case has been established, a way of assessing alternative scenarios and finding the optimum has to be established. A mathematical model has been used to find the optimum

location for filling stations throughout Europe. Having the optimum scenario in mind, different variations and deviations from it have been considered. The third and last step is to suggest an appropriate solution, which is in this case, a solution that is feasible and closest to the optimum. Figure 3.1 below illustrates these steps.

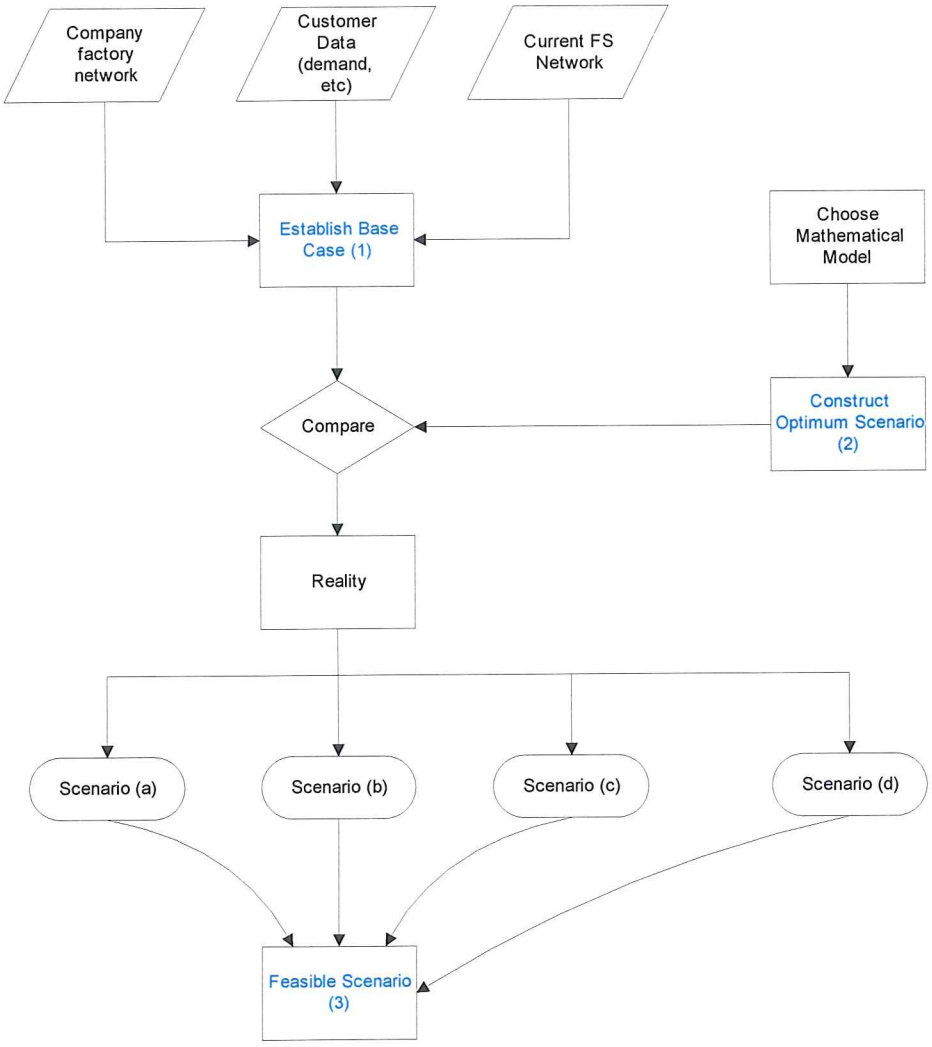


Figure 3.1, Methodology Flowchart

3.5.1 Base Case Understanding

The first thing that had to be done was to understand the current operations and the existing company's infrastructure network as well as the company's customer network. This was done to provide a basis for comparison between the base case and the optimum scenario to be constructed. In order to do that the various techniques were employed. These included quantitative and qualitative techniques.
Firstly a complete set of data on the customers and the infrastructure of the company were retrieved from the company and this data was analysed. This data was mainly in spreadsheet format and consisted of demand, location, origin of pigment and several other very useful pieces of information about the customers. When the data was not complete or vague, informal interviews with members of staff and the managers of the company at the logistics and sales departments were conducted. This provided the information that was missing and gave food for thought highlighting major issues within the European Bulk Distribution Network of the company.

3.5.2 Constructing the Optimum Scenario

In order to find the optimum number and locations of the filling stations quantitative methods were used. In this paragraph the reasons why the specific model was chosen are going to be presented along with a brief explanation of the model itself.

In order to find the optimum location and number of the filling stations the company set some ground rules. These were to completely ignore the existing filling stations and find the optimum number and location of filling stations taking into account the existing factory network and the customer network only. With these ground rules it was decided to use the infinite set approach to the depot location problem. Since constructing the optimum scenario involved locations new to the country specific hauliers and the company, informal interviews were conducted with the hauliers in

Before the third step of this process is explained, the way the relative position of the customers to the initial depot location was found, must be explained. This was done in the following manner. The area of the map containing the customers for each filling station was printed out and a Cartesian coordinate system was drawn on the map. The relative locations in space according to the respective Cartesian coordinates of the customers were recorded and these coordinates were inputted into equations (2.8, 9) to find the initial depot location using the centre of gravity method.

The third step of the setup for the initial solution was to calculate the straight-line distances of the customers from the initial filling station location. These distances were calculated using the routeing software Microsoft AutoRoute Express 2003®. These distances could have also been calculated on the printed maps taking into account each time the scale of the maps.

The fourth and last step of setting up the initial solution was to determine whether or not the respective customer demands are equal. From the data provided by the company it was evident that the customer demand was not equal and as such the customers were weighted according to their respective demand patterns. It was then a matter of minimizing the sum of these weighted straight-line distances. If the case was that the demand of the customers was equal amongst them, then the problem would reduce to a matter of reducing the calculated straight-line distances.

- ❖ Test for an improved solution

The next step of this iterative process is to evaluate the cost of the system with the filling station in the initial location calculated using equation (2.5).

The next step is, by using the Numeric-Analytic method explained in section 2.3.4 in chapter 2, to find a possible better location for the filling station.

The last step of this process is to evaluate the cost of the system, again by using equation (2.7) with the revised location for the filling station and compare it to the initial location cost. If this cost has decreased then the last two steps of this process must be repeated until there is no change in the cost.

After a series of iterations the cost will eventually decrease in very small increments as Willis (1977) and Eilon (1971) state. This indicates, they continue, that in the region of the optimum the cost curve is shallow. This shallowness of the curve has important practical implications. The filling station or depot can be moved a fair distance away to a more attractive or feasible location without appreciably increasing the transport costs.

3.5.3 Constructing the Feasible Scenario

Having constructed the optimum scenario without taking into account the existing network of filling stations a refinement of the optimum scenario had to be done in order to make it feasible. Since one of the limitations of the infinite set approach is that the optimum location for a filling station could be on a non-feasible location like a mountain range the optimum locations of the filling stations were reviewed.
Conducting informal interviews with the supply chain managers of the company and the country specific hauliers the feasible locations for the filling stations were selected and the total distribution cost of the system was calculated using these feasible locations for filling stations. This selection is discussed in detail in chapter 6.
During the construction of the feasible scenario, there were several possible variations for filling station locations, and as such the cost of some clusters was calculated several times to take into account these variations.

4 Chapter 4 – Base Case

As mentioned in Chapter 1 the Company has an extensive distribution Network throughout Europe to serve their customers that take pigment in bulk. In the following paragraphs, an attempt will be made to describe the current operations of the Company in detail.

4.1 The Company's Distribution Network

The company's Distribution Network comprises of the manufacturing sites and the Filling stations it holds throughout Europe. The Company has five manufacturing sites, and as mentioned previously in Chapter 1, there are 2 in the UK and one respectively in Italy, Spain and France. There are also eight Filling stations throughout Europe that act as depots and filling stations that fill tankers with bulk pigment.

4.1.1 The Factories

Very recently the Company had undergone a rationalisation of their manufacturing sites producing only 2-3 grades of pigment in each site out of the 10 that are sold in bulk. Figure 4.1 illustrates the locations of the manufacturing sites on the European map.

4.1.1.1 Greatham Manufacturing Site

Greatham is located in the North – East of England in Teesside, just north of the city of Newcastle. Greatham manufacturing site, along with the Grimsby manufacturing

site, serve most of the UK bulk customers, but also provide other filling stations in Europe with pigment. The grades manufactured in the Greatham site are:

Grade	Quality	Grade	Quality	Grade	Quality
TC 90	PR	TR 81	PR	TC 30	PR
TC 90	ST	TR 81	ST	TC 30	ST

Table 4.1, Grades and Quality of TiO_2 Produced at Greatham Manufacturing Site



Figure 4.1 European Map showing the locations of the manufacturing sites

4.1.1.2 Grimsby Manufacturing Site

Grimsby is located in the region of northeast Lincolnshire in England just south of the city of Hull. This manufacturing site together with the Greatham manufacturing site serves most of the UK customers but also provides other filling stations with the grades it produces. The grades and quality of these that are manufactured in Grimsby are:

Grade	Quality	Grade	Quality	Grade	Quality
FC 5	PR	HD 2	PR	TR 92	ST
FC 5	ST	HD 2	ST	-	-

Table 4.2, Grades and Quality of TiO_2 Produced at Grimsby Manufacturing Site

4.1.1.3 Calais Manufacturing Site

Calais is located in the north-eastern part of France on the coast on the English Channel. This site has a strategic location since the port of Calais can offer a great deal of flexibility both for procurement and for distribution. The Calais site serves in bulk directly from the factory a few customers all in France, and the rest of its production it sends to all the filling stations across Europe. In this manufacturing site the most popular selling grade, TR 92, is manufactured. The grades and quality of these grades that are produced in Calais are shown below:

Grade	Quality	Grade	Quality	Grade	Quality
TR 92	PR	TR 85	PR	C 300	PR
TR 92	ST	TR 85	ST	C 300	ST
TR 92	SS	-	-	-	-

Table 4.3, Grades and Quality of TiO_2 Produced at Calais Manufacturing Site

4.1.1.4 Huelva Manufacturing Site

Huelva is located in the south-southwest of Spain on the coast of the Gulf of Cadiz. This site, unlike the previous ones, does not serve any customers in bulk directly from the production plant. There are no facilities in Huelva in order for a tanker to be loaded and as such all of the product goes to filling stations and then transported by tankers to all of the respective customers. The grades and quality of these grades that Huelva produces are shown below:

Grade	Quality	Grade	Quality
TR 28	PR	FC 5	PR
TR 28	ST	FC 5	ST

Table 4.4, Grades and Quality of TiO_2 Produced at Huelva Manufacturing Site

4.1.1.5 Scarlino Manufacturing Site

Scarlino is located in the centre to the north of Italy on the west coast to the south of Genoa. This site like the Huelva site in Spain does not have the ability to load tankers with bulk pigment. It too has to pack all of the pigment and transport it a few Kilometres south to the Italian filling station. This site also produces the best selling grade of the Company, TR 92, but only the premium quality grade of it. The grades and quality of the grades produced in the Scarlino site are shown in table 4.5.

Grade	Quality	Grade	Quality
XL	PR	TR 92	PR
XL	ST	-	-

Table 4.5, Grades and Quality of TiO_2 Produced at Scarlino Manufacturing Site

4.1.1.4 Huelva Manufacturing Site

Huelva is located in the south-southwest of Spain on the coast of the Gulf of Cadiz. This site, unlike the previous ones, does not serve any customers in bulk directly from the production plant. There are no facilities in Huelva in order for a tanker to be loaded and as such all of the product goes to filling stations and then transported by tankers to all of the respective customers. The grades and quality of these grades that Huelva produces are shown below:

Grade	Quality	Grade	Quality
TR 28	PR	FC 5	PR
TR 28	ST	FC 5	ST

Table 4.4, Grades and Quality of TiO_2 Produced at Huelva Manufacturing Site

4.1.1.5 Scarlino Manufacturing Site

Scarlino is located in the centre to the north of Italy on the west coast to the south of Genoa. This site like the Huelva site in Spain does not have the ability to load tankers with bulk pigment. It too has to pack all of the pigment and transport it a few Kilometres south to the Italian filling station. This site also produces the best selling grade of the Company, TR 92, but only the premium quality grade of it. The grades and quality of the grades produced in the Scarlino site are shown in table 4.5.

Grade	Quality	Grade	Quality
XL	PR	TR 92	PR
XL	ST	-	-

Table 4.5, Grades and Quality of TiO_2 Produced at Scarlino Manufacturing Site

4.1.2 The Filling stations

A filling station is a site with storage area for the stock holding and a rig for gravity filling the tankers for bulk distribution. This rig is a platform at a height above the total height of the tanker with protective rails and harnesses and a suction pump used to reduce or eliminate the dust generated by filling the tanker.

It will be easier to understand this by describing the process of filling a tanker at the filling stations. The tanker is driven in the filling station and under the platform. Two workers at the filling station wearing the appropriate protective gear climb up on the platform. From the platform and wearing a harness the workers open the hatches of the tanker and place a hoper in one of the hatches and attach the suction pump on the adjacent hatches to prevent excess dusting from the filling. Another worker driving a forklift truck lifts a Tiotainer (1 tonne big bag) above the tanker and lowers it above the hopper. The worker on the platform pulls on a cord on the Tiotainer and the pigment is discharged into the hopper and into the tanker. After the Tiotainer is empty the bag is unhooked from the forklift truck and is folded neatly for returning to the Company for reuse.

These filling stations are of great importance because in these, the packed goods are transformed into bulk goods for delivery to the customers. As mentioned in chapter 1, there are 8 filling stations throughout Europe. In reality there are only 5 actual filling stations, but at three manufacturing sites tankers can be directly filled, and as such these manufacturing sites are regarded as filling stations.



Figure 4.2, European Map showing the locations of the Filling Stations

Figure 4.2 above illustrates the locations of the filling stations throughout Europe, including the manufacturing sites that are regarded as filling stations.

The filling capacity of the filling stations is the same for all of the filling stations and it is about 4 tankers per day, although this figure could increase to 5 tankers per day if that was necessary. Table 4.6 below shows the average stock held per month and per annum for each filling station.

Filling Station	Avg. Stock pa (tonnes)	Avg. Stock/Mth. (tonnes)[2]
Grosseto	3500	286
Santander	1000	84
Wesel	1000	84
Turku	1000 - 1300	100
Gothenburg	3500 - 4200	320

Table 4.6, Average Stock held at each FS pa and per Month (in tonnes)

4.2 The Company's Customer Network

As this project is concerned with only the bulk European network, the customers that receive pigment in bulk will only be considered. The company currently has 78 customers in 12 countries in the European continent to which pigment is supplied in bulk. The annual tonnage that the customers receive varies greatly and ranges between 100 and 10,000 tonnes, with an average of around 1,500 tonnes per annum[3].

As it was seen from chapter 1 in order to reduce the cost of the European Bulk Delivery Network the tanker journeys from the filling stations to the customers have to be minimised. In order to achieve this Filling stations have to be strategically placed throughout Europe dependant on customer location and demand. For this reason customers were clustered using the location and demand criteria.
With the exemption of the customers in Denmark, Sweden and Finland, which form a cluster of their own, the rest of the Company's customers, one could say, are situated in neatly formed clusters around the continent with some exceptions. The clustering of the customers as well as the classification of customers by the Company will be discussed in the following paragraphs.

4.2.1 Customer Groups

The Company has classified their customers into 3 main categories; A, B or C depending on their importance to the company. Within the A category there are 2

[2] The Average was calculated using the actual stockholding figures from 01/03 to 05/03
[3] These figures were calculated using the Forecasted figures for sales of 2004

4.4 Bulk Movements

In the context of this thesis Bulk Movements are the movements of the packed pigment from the factories to the filling stations. This movement is termed like this because this pigment is eventually going to be transported in bulk from the filling

Manufacturing Plant	Filling Station	Grade
Greatham	Wesel	TC 90/TC30
	Grosseto	TC 90/TR81
	Santander	TC 90/TR81
Grimsby	Wesel	FC 5
	Calais	FC 5/HD 2
	Gothenburg	HD 2
Calais	Gothenburg	TR 92/TR 85
	Grosseto	C 300
	Santander	TR 92/TR 85
	Turku	TR 85
	Wesel	TR 85
Huelva	Wesel	TR 28
	Grosseto	FC 5
	Santander	TC 90/FC 5
	Calais	TR 28
Scarlino	Wesel	XL
	Grosseto	XL/TR 92
	Santander	XL

Table 4.8, Grades shipped from factories to filling stations

stations to the customers. Most of the manufacturing sites deliver packed pigment to mostly all of the filling stations. European maps with these Bulk Movements are shown in appendices 1-5. Table 4.8 above provides an overview of what grades from what manufacturing plants are transported to which filling station.

4.5 Cost of Current Operations

As described previously throughout this chapter the total cost for delivering bulk pigment to customers in Europe is comprised of three parts. This division of costs yields from the three distinct activities that the pigment undergoes from its despatch from the factory through to the delivery to the customer. These are the trunking from the factory to the filling station, the storage of the pigment in the filling station and the subsequent filling of the tankers, and lastly the tanker journey of the bulk pigment to the customer. In order to illustrate how much more expensive the third activity is – the delivery of pigment in tankers – when compared to trunking the pigment to the customer table 4.9 was constructed. For a random cluster – Wesel in this case – the cost of two different methods of transporting pigment to the customers is compared. The first method, called "Bulk", is when pigment is transported packed from the factory to the filling station and subsequently the pigment is loaded into tankers and then transported to the customers in bulk. The second method, called "Packed", is when packed pigment is directly transported from the factory to the customer.

Table 4.9 below illustrates two things. Firstly the difference in cost of transporting pigment in packed form and transporting pigment in bulk via the filling stations and secondly the reason why the minimisation of the Kilometres that each tanker travels would yield the greatest reduction in the overall cost of serving customers in bulk. This second statement is indirectly drawn from table 4.9, when one takes into account that the distance travelled by using both methods of pigment transportation is roughly the same. It can thus be understood that the same kilometres travelled by the tankers costs more than when normal trunking is used. In order to illustrate this point more clearly the figures for the costs of one cluster will be used. The figures in table 4.9 are shown in euros per tonne. The reason behind this is the different unit loads of the articulated trucks and tankers. The maximum payload for the articulated vehicles is 25 tonnes and the maximum payload for the tankers is 27 tonnes. Thus the unit (€/t) is the most appropriate unit in order to have a meaningful comparison.

Wesel Cluster		
Average Cost Bulk	Average cost Packed	Difference
81.45 €	40.59 €	40.86 €

Table 4.9, Difference in cost between Packed and Bulk Pigment deliveries

No standard tariff was given to the author concerning handling costs at the filling stations from the hauliers that operate them. The figures given were in the context of euros per tonne handled at the filling stations. Each haulier has given a figure for every filling station. From these figures it can be deduced that the difference shown in table 4.8 above can be attributed to the very expensive tanker journey rather that the handling costs. The handling costs at Wesel filling station are 21 euros per tonne handled and the average cost for the tanker journey from the filling station to the customers is 48 euros per tonne. The rest of these figures are shown in appendix 6. It must be noted that Wesel filling station has the highest figure for handling costs with the next highest being Grosseto in Italy with 14.11 euros per tonne handled.

For comparative purposes the total distribution cost of the current operations of the company are going to be presented below. The total figures for cost are going to be presented with the handling costs, tanker costs, and trunking costs added all together. Thus in table 4.10 the total current distribution costs are shown divided into the clusters.

Cluster	Cost
Grosseto	933,085.89 €
Santander	1,493,993.59 €
GM/GY	974,911.22 €
Turku	153,367.50 €
Kungsbacka	186,831.00 €
Calais	2,078,587.76 €
Wesel	1,638,966.20 €
Total Cost	**7,459,743.16 €**

Table 4.10, Total cost of current operations

Introducing new filling stations in better locations would reduce the tanker journeys, which are the most expensive activity of the three comprising the bulk deliveries. In the following chapter the optimum scenario of the number and locations of filling

stations will be presented as these were calculated using the mathematical model described in chapter 3.

5 European Bulk Distribution Network Optimisation

In this chapter the optimum scenario of the European Bulk Distribution network of the Company will be presented. Chapter 6 will be concerned with the feasible solution of the European network optimisation. By using the mathematical model, explained in the following section, and the whole methodology described in chapter 3 the optimum location of filling stations for each cluster was determined. A part of this chapter is the presentation of the cost associated with the serving of the company's customers using this network of filling stations. Having the minimisation of the tanker travel distance in mind the following clusters and subsequent filling stations were determined. At the end of this chapter a comparison between the current and the optimum scenario of Filling Stations will be presented.

5.1 Centre of Gravity Analysis

In this paragraph, the implementation of the Centre of Gravity analysis and an explanation of what was done and how the model was implemented are going to be presented.

The model as explained in the literature review – Ch 2 – takes into account the relative distances of the customers with a proposed location of a warehouse and the demand of each customer. Thus the first set of data that was gathered was the demand of each customer and the distances mentioned above. The demand for each customer was given to the author by the Company. The method by which the distances were calculated is going to be explained in a later paragraph. Both the Kilometric distances and the demand data mentioned above can be found in appendices 7a and 7c respectively.

As mentioned previously in paragraph 4.2, the need to use clusters in this analysis had risen. The first objective of this project is to find the optimum locations for filling

stations and the second objective is to reduce the cost of operations. Each group of customers that was to be served by one filling station had to be considered separately.

5.2 Optimum Number and Location of Filling Stations

With the implementation of the model 13 clusters were formed. As aforementioned in the previous chapters the Company's customers were grouped on the map forming clusters amongst them. This made the selection of the clusters an easy task. The customer clusters and the corresponding filling station for each cluster are described in the following chapters. It must be noted again that the aim of the clustering of the customers was to minimise the tanker travel and that some of the locations determined by the model are not necessarily locations where the company can install a filling station.

5.2.1 Customer Clusters and location of Filling Stations

As it was mentioned in the preceding paragraph there were 13 clusters formed. The existing filling stations were not taken into account and new locations for Filling Stations were determined with the aid of the mathematical model. Each of the clusters determined will be examined in the following paragraphs.

5.2.1.1 Spanish and Portuguese Clusters

In the current operations the Company serves the whole of the Iberian Peninsula from a single Filling Station in the northern part of Spain in Santander. The Spanish customers could be clustered into 3 clusters; North, East and South. Portuguese customers formed a cluster of their own incorporating a Spanish customer situated on the north border of Portugal. Figure 5.1 illustrates these 4 clusters on the Iberian Peninsula.

Along these lines of thinking, the customer clusters were constructed by grouping customers in terms of their distance between them and the morphology of the area these customers were in. this led to the formation of 13 clusters.

The location of the clusters of customers and an initial warehouse were recorded on a digital map with the aid of the Microsoft® AutoRoute 2003 software package. Each cluster on the map was printed out and a Cartesian coordinate system was constructed for each cluster. At this point it must be noted that the scale of these maps was irrelevant because it was the relative distance between the customers and the warehouse that was of interest. From these coordinate systems the coordinates of the customers were deduced.

The demand data that was provided by the Company was converted to a weighted demand for each customer in each cluster. This weighting was done by dividing the demand by an appropriate number in each cluster to compensate for the variation in demand of each customer.

The coordinates and the weighted demand for each customer were inserted into equations 2.6,7 and the coordinates provided were the coordinates for the optimum location of the warehouse, or filling station in this case. There are some limitations in this method which will be explained in the conclusions chapter. Nevertheless the location provided by the model gave a very close approximation to the true optimal location for the filling station. A worked-through example of this analysis and examples of the outputs of the model are given in Appendix 9.



Figure 5.1, Map showing the Spanish and Portuguese clusters

The arrows on figure 5.1 illustrate the straight line distance from the Filling Station to each customer. In the North Spanish cluster the optimum point for a Filling Station was close to Huarte-Araquil near the city of Pamplona. The North Spanish cluster comprises of 6 customers who in total have an annual demand of 6,614 tonnes. Figure 5.2 shows the North Spanish cluster in more detail. With the use of the zoomed in maps of each cluster the distance of the customers to the filling stations is more clearly illustrated.

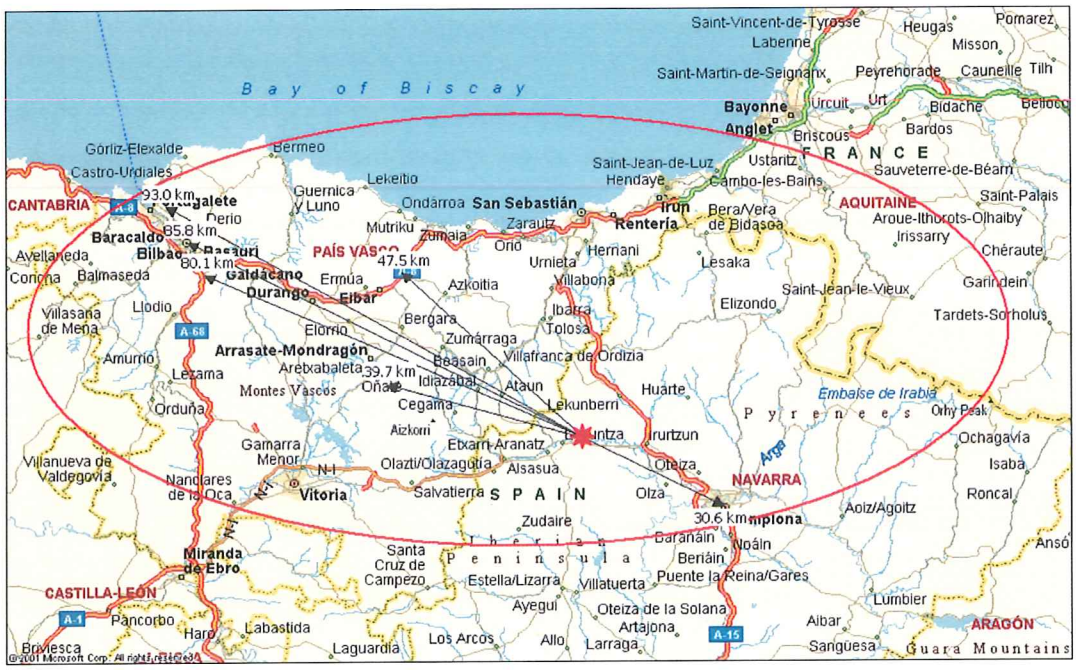


Figure 5.2, Map showing the North Spanish Cluster

The East Spanish cluster was in essence all the customers based in or around Barcelona. The model determined the optimum position for the filling station just at the outskirts of Barcelona. This cluster has 4 customers and their total annual demand sums up to 3,744 tonnes. Figure 5.3 illustrates this cluster.



Figure 5.3 Map showing the East Spanish Cluster

The South Spanish cluster comprises of 7 customers and their total annual demand is 3,329 tonnes. The optimum point for a filling station for this cluster is La Matanza in near the city of Albacete. The average tanker travel distance is greater that the two previous clusters and in fact fro the Portuguese cluster as well. This is due to the dispersion of the customers between them. Figure 5.4 shows the South Spanish cluster in more detail.



Figure 5.4, Map showing the South Spanish Cluster

The Portuguese cluster, which as aforementioned includes a customer in Spain near the north Portuguese border in Vigo, has 4 customers which have an annual demand of 2,237 tonnes. The optimum point for a filling station for this cluster was very close to the coast of Portugal near the city of Caniceira in the Coimbra province near the city of Aveiro. Figure 5.5 illustrates the Portuguese cluster in more detail.

It has been stated throughout this thesis that the activity that adds the most to the cost of the Bulk Delivery of the Company is the cost of the tanker. The longer the distance the tanker has to travel the greater the cost of that journey. To illustrate the difference in the distance that the tankers have to travel a comparative table is shown in table 5.1.



Figure 5.5, Map showing the Portuguese cluster

By introducing 4 filling stations in the Iberian Peninsula instead of one, it is obvious that the tanker journeys would be reduced a great deal. From table 5.1 it can be seen that there is actually a great difference in Kilometres travelled. In the base case the tankers travel for one leg of the journey – that is from the filling station to the customer – a total of 8,668 Km as opposed to the optimum of only 2,218 Km.

The tables showing the comparison between tanker travel distances in the optimum scenario and in the base case in this chapter all are constructed using the figure of travel distance for one leg of the journey. It must be reminded that the locations of the filling stations that were constructed with the Centre of Gravity model take into account two things in order to yield the weighted average distance; the distance of the customers relative to a reference point on the grid, and the demand of each customer. Thus the final location of the filling station is the optimum in regards of distance and demand. Thus the decision of using the figure for a single leg journey simplifies the calculations without compromising the validity of the results.

Customer	Cluster	Current (Km)	Optimum (Km)
Industrias Juno	North Spain	72	93
Esber	North Spain	77.3	85.8
Eurocolor	North Spain	82.5	80
Bernardo Ecenarro	North Spain	118	47.5
Ulma Hormigon Polimero	North Spain	122	39.7
Transcolor	North Spain	190	30.6
Duracolor	East Spain	524	23.3
Clariant Iberia	East Spain	542	11.6
Industrias Titan	East Spain	540	15.1
Barnices Valentine	East Spain	540	9.19
Productos Alp	South Spain	321	265
Faplisa	South Spain	343	264
Duraval	South Spain	493	84.6
Pinturas Decolor	South Spain	500	87.3
Jafep	South Spain	628	117
Eupinca	South Spain	691	121
Esvi	South Spain	630	181
Robbialac	Portuguese	690	185
Dyrup	Portuguese	690	185
CIN	Portuguese	473	85.8
Industrias Proa	Portuguese	422	207
Total		**8,688.80**	**2,218.49**
Average		**413.75**	**105.64**

Table 5.1, Comparison of tanker travel distances between Base Case and optimum – Spain

5.2.1.2 Italian Clusters

The Company currently serves the whole of the Italian customers from a single Filling Station in Grosseto, which is just South of the Italian Factory in Scarlino. Due to the singularity of the shape of Italy, two clusters were initially considered; a north and a south. After a closer review of the locations of the customers it was decided that there would be two north Italian clusters and one south Italian. Figure 5.6 shows these three clusters on the map.

The first cluster to be considered is the northwest cluster around Milan. In this cluster there are five customers. Most of the customers are situated in or around the city but there are also 2 customers that are a fair bit away from the rest. One is in Switzerland and one is in Genoa. Figure 5.7 shows this cluster in more detail.



Figure 5.6, Map showing the Italian clusters

In the Northwest Italian cluster the annual demand of these 6 customers is 4,708 tonnes. The optimum location for a filling station in this cluster is just west of the city centre of Milan. Figure 5.7 below shows the cluster in more detail.

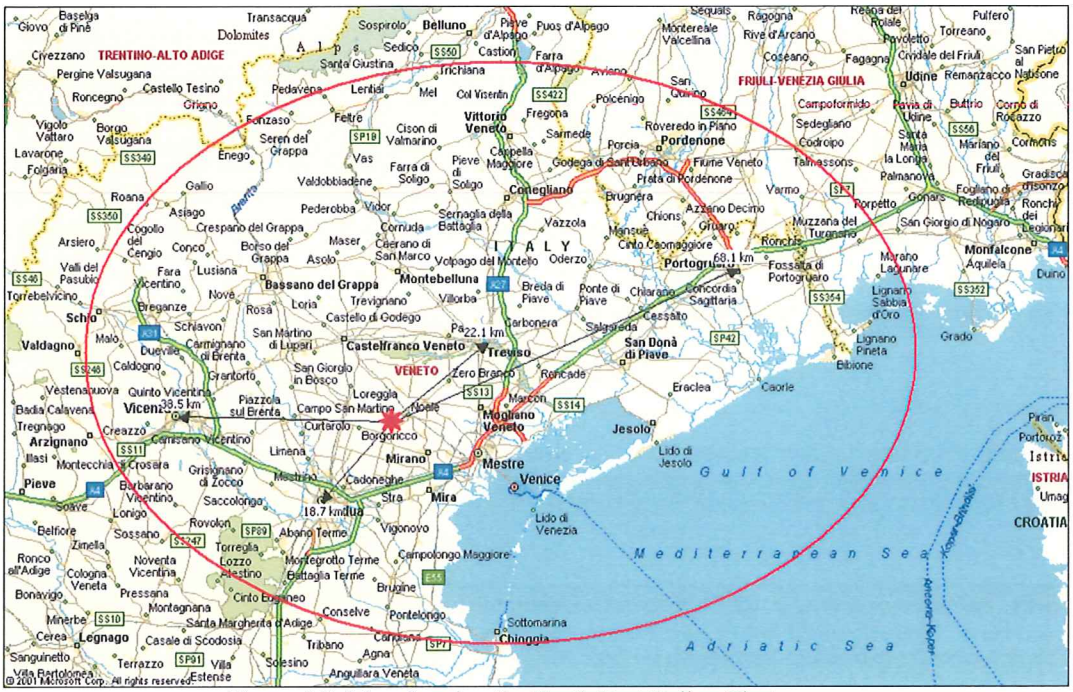


Figure 5.8, Map showing the North-East Italian Cluster

The last cluster in Italy is, as mentioned before, the south cluster. This is the biggest cluster in Italy, in terms of distance travelled, and serves 6 customers. The total annual demand of these customers amounts to 2,645 tonnes. The optimum location for this cluster, as shown from the model, is the city of Avezzano in the Abruzzo province. Figure 5.9 shows the south Italian cluster in more detail.

It is once more evident that having 3 filling stations instead of one in a country with land morphology like Italy would yield less Kilometres of tanker travel. This difference will be illustrated by a table comparing the tanker travel distances in the Base Case and in the optimum scenario.



Figure 5.9, Map showing the South Italian cluster

This table, table 5.2, follows the same philosophy as table 5.1 on page 47. The Kilometres that the tanker has to travel in the current scenario are shown next to the Kilometres that the tanker would have to travel in the case of the optimum scenario.

Customer	Cluster	Current (Km)	Optimum (Km)
Alcea az Lomarda Colori	North West (Milano)	340	12.5
Clariant	North West (Milano)	342	16.7
Boero Colori	North West (Milano)	257	123
J Colors (Milano)	North East (Milano)	351	10.3
VIBA	North West (Milano)	385	36.9
Eio Ag	North West (Milano)	533	193
ATS Color	North East (Padova)	363	68.1
Ard f.lli Raccanello	North East (Padova)	302	18.7
Fasso Uno	North East (Padova)	336	22.1
Cap Arreghini	North East (Padova)	311	38.5

Table 5.2, Comparison of tanker travel distances between Base Case and optimum - Italy

Customer	Cluster	Current (Km)	Optimum (Km)
Lafarge Paints	South Italy	340	149
Di Donato (aka Azimut)	South Italy	253	84.4
Ind Chimica Adriatica	South Italy	198	150
Chreon (Lechler)	South Italy	111	151
Baldini Lafarge	South Italy	128	304
J Colors (Pisa)	South Italy	116	305
Total		**4,666.00**	**1,683.20**
Average		**291.63**	**105.20**

Table 5.3, Comparison of tanker travel distances between Base Case and optimum - Italy (cont)

Similar results can be seen from this table as from table 5.1. There has been a massive reduction in tanker travel distances in the case of the optimum scenario as compared to the travel distances in the case of the base case. Let us note that, as described in chapter 4, the whole of Italy is served by a single filling station which is situated in Grosseto just south of the Scarlino manufacturing site.

5.2.1.3 German Cluster

When constructing the German cluster in the model, the only Belgian customer of the Company was included in this cluster. Cabot, in Pepinster, is the largest customer that the company has with an annual demand of around 11,000 tonnes. This demand is even larger than that of a whole cluster as we have seen. In the base case this customer is served directly from the Calais factory. Figure 5.10 shows the German cluster on the map. The optimum location for a filling station for this cluster, as calculated with the use of the model, was a site just south of the city of Monchengladbach and this cluster has 9 customers with an annual total demand of around 24,063 tonnes. As it can be seen from figure 5.10, the locations of the German customers form a tidy cluster with the exception of one customer west of Hamburg in Pinenberg. The closest filling station to that customer is the German one and as such this customer will be served from that one.



Figure 5.10 Map showing the German Cluster

Since the customer in Pinenberg has a low annual demand and the customer in Pepinster in Belgium has a very large annual demand, the optimum location for a filling station in this cluster is drawn towards the later customer. As with the previous clusters that were described a comparative table showing the reduction of the tanker travel distances.

Customer	Cluster	Current (Km)	Optimum (Km)
Brillux	Germany	78.8	125.0
Kluthe	Germany	28.5	48.5
Polyplast	Germany	35.2	38.0
Akzo	Germany	85.0	43.0
Cabot	Germany	283.0	76.0
Kalle Pentaplast	Germany	162.0	125.0
FDT Lafarge	Germany	276.0	233.0
Rowa	Germany	308.0	363.0
Total		**1,256.50**	**1,051.50**
Average		**157.06**	**131.44**

Table 5.4, Comparison of tanker travel distances between Base Case and optimum - Germany

Table 5.3 above illustrates the difference between the base case and the optimum scenario in terms of Kilometres travelled by the tankers. It can be seen that there is a slight decrease in Kilometres travelled in the optimum scenario, if compared with the very large decreases in the previous clusters that were examined. This can be attributed to the fact that the current filling station, in Wesel, is near to the optimum location determined by the model and as such there is not a great deal of improvement to be done.

5.2.1.4 French Cluster

This cluster as the name suggests is the cluster with the French customers. There are 11 customers in this cluster with a total annual demand of around 10,600 tonnes. The optimum location for a filling station for this cluster is Grandvilliers which is situated about 40 Kilometres southwest of Amiens. Figure 5.11 shows the French cluster on the map.

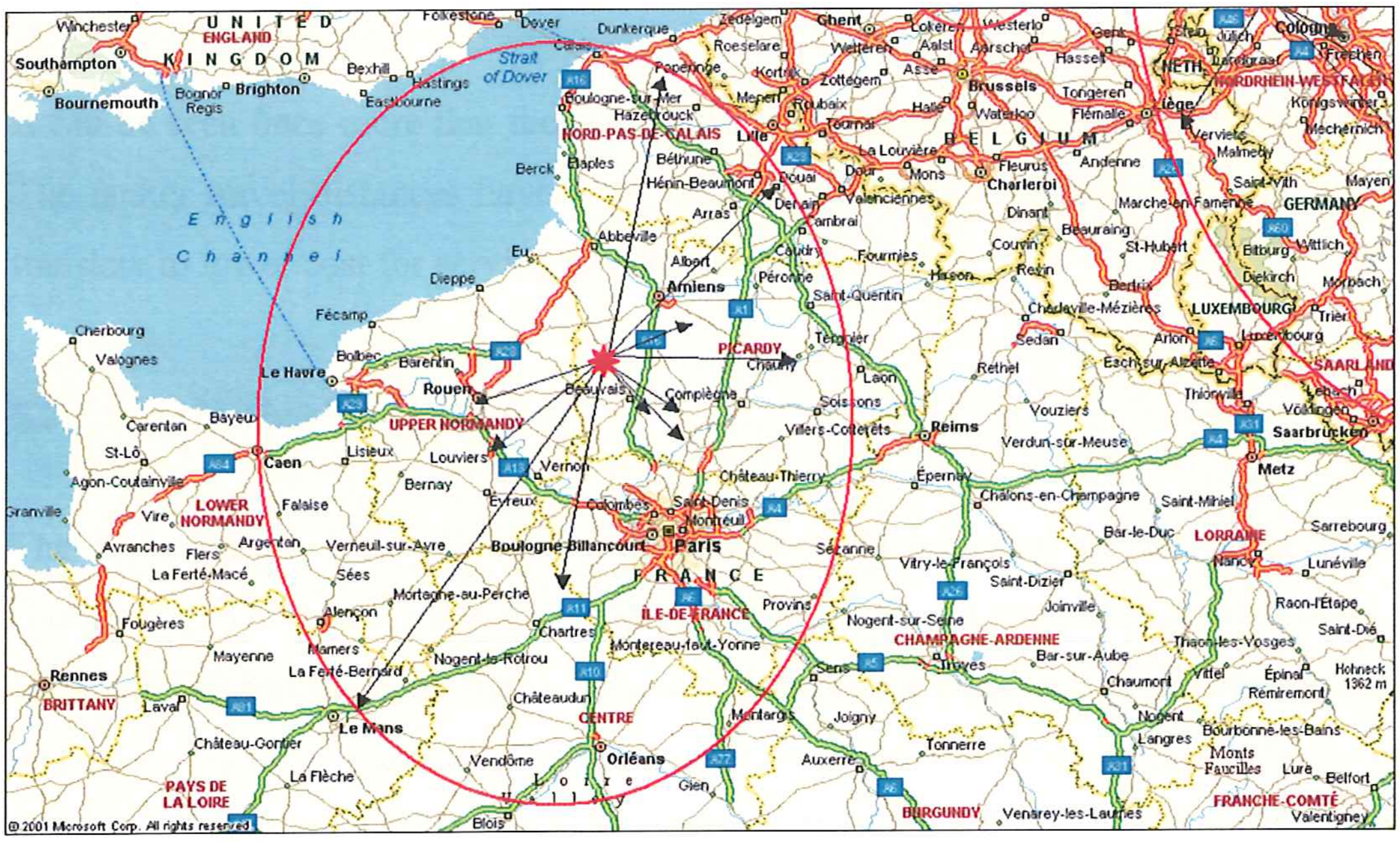


Figure 5.11, Map showing the French cluster

In the current scenario – base case, these customers were served form the filling station, in the manufacturing plant, in Calais. Table 5.5 illustrates the difference in tanker travel distance between the base case and the optimum scenario.

Customer	Cluster	Current (Km)	Optimum (Km)
Merckeghem	France	34.0	140.0
Douai	France	109.0	116.0
Moreuil	France	140.0	44.5
Noyon	France	181.0	92.0
Clermont	France	180.0	44.5
Montataire Creil	France	194.0	55.0
Villers Saint Sépulcre	France	179.0	35.0
Grand-Quevilly	France	183.0	65.0
Louviers	France	202.0	71.0
Epernon	France	264.0	115.0
Fatines	France	345.0	208.0
Total		**2,011.00**	**986.00**
Average		**182.82**	**89.64**

Table 5.5, Comparison of tanker travel distances between Base Case and optimum – France

It can be seen once more that there is a substantial difference between the two cases. The tanker travel distances have been reduced to half the original ones, which will translate to lower cost for serving these customers in bulk.

5.2.1.5 Netherlands Cluster

The Netherlands cluster is one of the smallest clusters that we are going to be considering. This cluster has 4 customers and the annual demand of these clusters is around 1,500 tonnes. This figure does not include one customer in the Netherlands that has an annual demand of around 3,600 tonnes who takes pigment from the Grimsby factory ex works. Figure 5.12 shows the Netherlands cluster on the map. The optimum location for a filling station for this cluster is the small town of Loete.

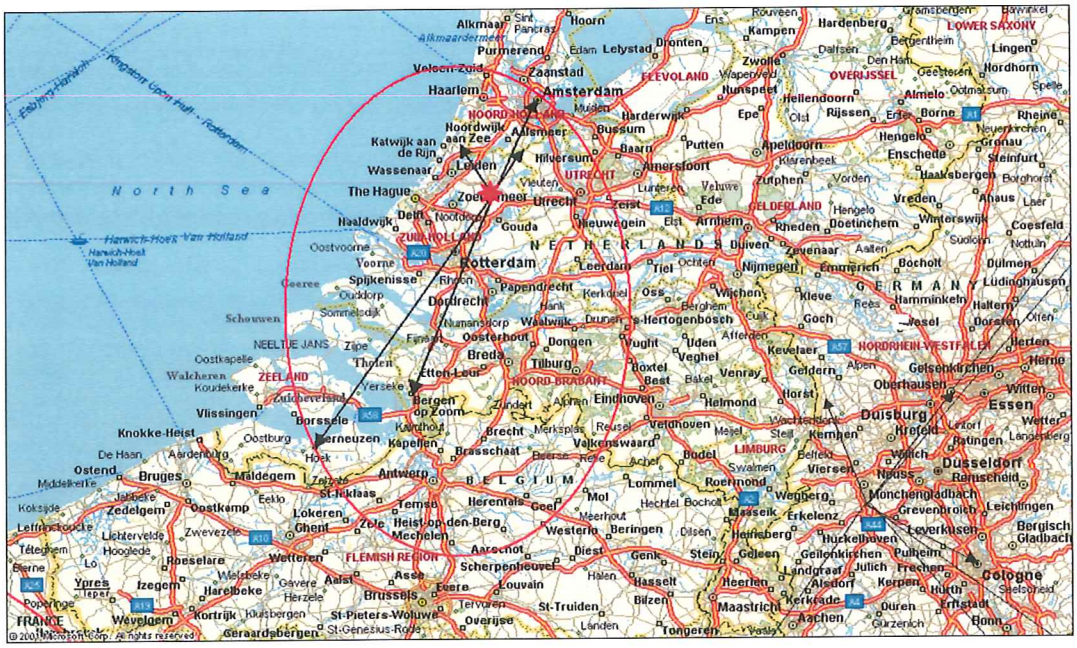


Figure 5.12, Map showing the Netherlands cluster

The customers in this cluster were served from different filling stations. Two customers were served from Calais and the remaining two were served from Grimsby. This constituted in large tanker travel distances, and as it is going to be shown in table 5.6 there has been a substantial reduction in travel distances when compared with the optimum scenario.

Customer	Cluster	Current (Km)	Optimum (Km)
Sigma	Netherlands	263.0	35.0
Sigma (Atofina)	Netherlands	-	-
Akzo	Netherlands	234.0	19.0
GEP	Netherlands	181.0	73.0
DOW	Netherlands	146.0	104.0
Total		**824.00**	**231.00**
Average		**206.00**	**57.75**

Table 5.6, Comparison of tanker travel distances between Base Case and optimum - Netherlands

5.2.1.6 UK Cluster

The UK cluster has a few customers and a lot of demand. In this cluster there are 5 customers and their annual total demand is around 33,400 tonnes. These customers are currently served from the two UK filling stations/factories; Greatham and Grimsby. The model determined as the optimum location for a filling station a site just southeast of the city of Grantham.

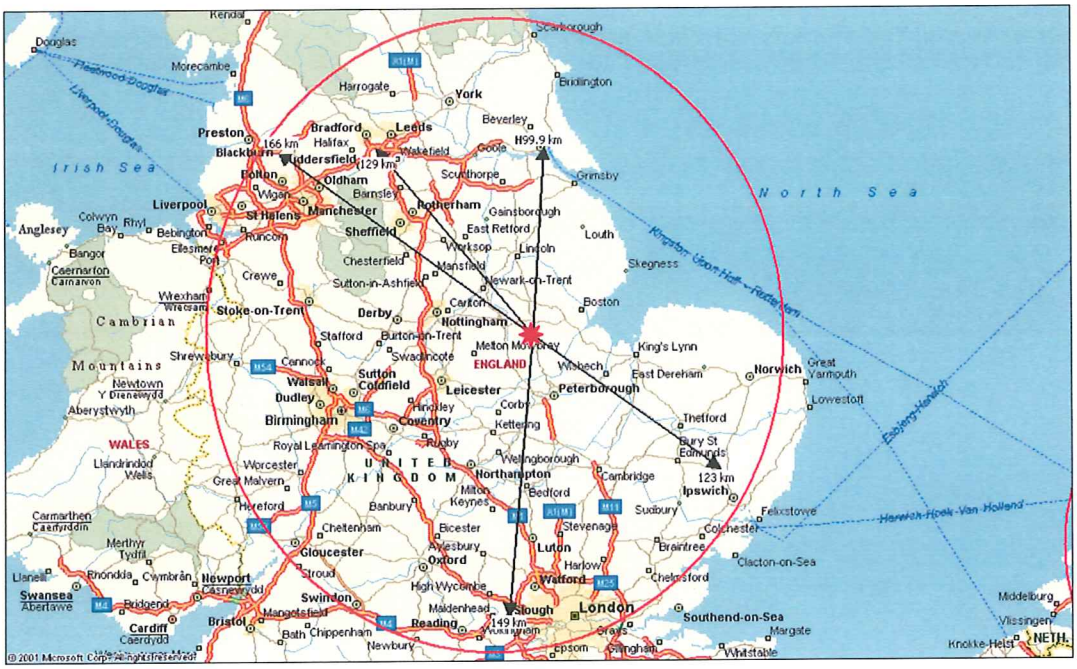


Figure 5.13, Map showing the UK cluster

Figure 5.13 above illustrates the UK cluster on the map with the arrows going to the 5 customers originate from the optimum location for a filling station near Grantham. As with the previous clusters a comparative table, table 5.7, is shown below to illustrate the difference in tanker travel distances between the base case and the optimum scenario. Table 5.7 differs though from the previous comparative tables. In this table there is one more column inserted. In the UK the 5 customers that are served in bulk are served from both the factories because most of them take more than one grade of pigment making it difficult to measure the travel distances of the

tankers. That is why in table 5.7 customers are repeated and there is the name of the factory that the pigment is manufactured next to the customer name.

Customer	Factory	Cluster	Current (Km)	Optimum (Km)
Akzo Darwen	Grimsby	UK	162.00	165.00
Akzo K-U-H	Grimsby	UK	30.00	100.00
ICI Slough	Grimsby	UK	240.00	149.00
ICI Stowmarket	Grimsby	UK	166.00	123.00
Akzo K-U-H	Greatham	UK	124.00	100.00
Kalon	Greatham	UK	112.00	129.00
ICI Slough	Greatham	UK	365.00	149.00
ICI Stowmarket	Greatham	UK	312.00	123.00
Total			**1,511.00**	**1,038.00**
Average			**188.88**	**129.75**

Table 5.7, Comparison of tanker travel distances between Base Case and optimum – UK

5.2.1.7 Nordics Clusters

The Nordics clusters are the last clusters that were analysed. There are two clusters formed in this area, the Gothenburg (Kungsbacka) cluster that has one customer and the Turku cluster that has one customer. The analysis of these two clusters, like all of the previous ones was done taking into account the actual sales volumes of 2002. The results presented hereafter in this paragraph take into account the above factors. Figure 5.14 shows the Nordics clusters on the map.

The Gothenburg (Kungsbacka) cluster, as mentioned above, has two customers with a total annual demand of 1,647 tonnes. The Model showed the optimum location for a filling station in this cluster to be a location very close to the original site in Gothenburg (Kungsbacka). This would yield almost no change in the distances travelled but the tankers.

Turku cluster has only one customer and as such it was not possible to implement the model in finding a better/ optimum location.



Figure 5.14, Map showing the Nordics Clusters

Table 5.8 is a comparative table showing the difference between the tanker travel distances in the base case and in the optimum scenario. As mentioned above the optimum location for a filling station is very close to the original location of the filling station and very small differences are anticipated. It must be noted that the optimum location for the filling station was calculated with 2 other customers in the model that are no longer customers of the company.

Customer	Cluster	Current (Km)	Optimum (Km)
Jotun	Gothenburg	214	212
Flugger	Gothenburg	293	273
Tikkurila	Turku	164	164
Total		**671.00**	**649.00**
Average		**223.67**	**216.33**

Table 5.8, Comparison of tanker travel distances between Base Case and optimum – Nordics

5.2.2 Cost of Optimum Scenario

The cost of this optimum scenario is calculated, similarly to the way that the cost was calculated for the base case, by dividing the cost into three parts. The trunking cost the handling cost at the filling stations and the tanker cost. The steps that were followed to calculate the total cost of the optimum scenario will be presented hereafter.

A hypothetic customer is going to be analysed as an example in order for these steps to be fully understood. The first step in this calculation was to determine the number of journeys needed to supply each customer with their annual demand. After the factory and the filling station locations have been established for the particular customer – and their respective distances, their annual demand is divided by the maximum load of the truck and of the tanker for the respective trunking from the factory to the FS and the tanker travel from the FS to the customer. This will yield the number of trunking journeys and tanker journeys needed for the fulfilment of the customer's annual demand.

Each haulier has provided us with approximate costs per journey for both means of transport. In order to reduce the complexity of the calculations these costs were reduced to the unit (€/tonne). This unit was chosen to be the base cost unit for all calculations. The hauliers have also provided us with a handling cost. This cost was also in the form of (€/tonne handled), so in order to find the total handling cost for each customer, the annual demand (in tonnes) was multiplied by the cost given.

In essence this analysis yielded three costs; the trunking cost, the tanker cost and the handling cost. The sum of these three costs was the total cost for each customer.

There are some deviations from this methodology in some cases though. The haulier serving the customers in the Iberian Peninsula was unable to provide us with costs from the optimum locations for the filling stations, but gave us an approximation

using the kilometric distances. In this case the transport costs were calculated using a distance – cost equivalent.

For the purposes of presenting the cost of the optimum scenario, the costs are grouped by cluster and by activity. That is to say, as it can be seen in table 5.9, that the cost figure is one figure comprised from the three distinct activities and this cost figure is segmented by cluster.

During the course of this project it came to the knowledge of the Company that from 2004 onwards an extra road tax will be inflicted to every HGV travelling through Germany. This new Road Tax – quoted hereafter as the German Road Tax[4] – will be around €0,124 per Km travelled. In order to calculate the cost of this German Road Tax, the total number of Km travelled through Germany by both trucks and tankers is calculated and this figure multiplied by the unit cost. The spreadsheet analysis of the aforementioned is shown in appendix 10.

Cluster	Cost
Cornaredo (Milano)	566,480.84 €
Briana (Padova)	53,218.59 €
Avezzano	91,267.05 €
Huarte-Araquil (Pamplona)	367,807.06 €
Barcelona	280,293.29 €
La Matanza (Albacete)	362,845.10 €
Caniceira (Coimbra)	235,591.85 €
Grantham	974,911.22 €
Turku	153,367.50 €
Kungsbacka	116,224.75 €
Loete (Alphen aan den Rijn)	78,264.64 €
Grandvilliers	582,111.20 €
Monchengladbach	2,740,424.50 €
German Road Tax	22,619.34 €
Total Cost	**6,625,426.93 €**

Table 5.9, Total cost of Optimum scenario

[4] According to A&M (2003), Excess Road Tax will also apply to HGV's traveling through Austria with a cost of €0, 24/Km.

Table 5.10 below, provides a breakdown of the above costs into the three activities; Trunking costs, tanker costs and handling costs. The German Road Tax is also inserted in table 5.10

Optimum Scenario	
Trunking Cost (Primary)	3,075,612.85 €
Handling Cost	1,351,869.33 €
Tanker cost (Delivery)	2,175,325.41 €
German Road Tax	22,619.34 €
Total Cost	6,625,426.93 €

Table 5.10, Broken-down Costs for optimum scenario

5.3 Comparison between Current and Optimum Scenario

The mathematical model yielded new locations for the filling stations and the analysis had the aim of reducing the tanker travel distances since this activity is the most costly one of the three comprising the bulk serving of the customers. The total cost is comprised of the trunking costs, the handling costs and the tanker costs.

The trunking cost is the cost of transporting packed pigment in Tiotainers from the manufacturing plant to the filling station. Handling costs are the costs of handling the pigment in the filing station. This cost comprises the cost of handling the bags within the warehouse, storing the bags in the warehouse and filling the tankers with pigment. The tanker costs are the cost of sending the tanker from the filling station to deliver pigment to the customer. Table 5.11 illustrates the difference in Kilometres travelled in the base case and in the optimum scenario by the tankers.

	Base Case	Optimum
Kilometres Travelled	19,393.1	6,412.0

Table 5.11, Kilometres travelled by the tankers in Base Case and Optimum

It can be seen from table 5.11 that there is a great reduction in the overall distance travelled from the tankers. The distance travelled from the tankers in the optimum scenario approaches one third of the distance travelled in the Base case. Having an impressive reduction like this in the tanker travel distances does not mean though that there will be an analogue reduction in the cost of the operations as explained in chapter 2 – Literature Review. In this case the trunking travel distances have been increased by putting a filling station closer to the customers and further away from the manufacturing plants.

	Base Case	Optimum Scenario	Difference
Trunking Costs	2,881,194.15 €	3,075,612.85 €	194,418.71 €
Handling Costs	1,352,003.09 €	1,351,869.33 €	-133.76 €
Tanker Costs	3,226,545.93 €	2,175,325.41 €	-1,051,220.52 €
German Road Tax	43,652.81 €	22,619.34 €	-21,033.48 €
Total Cost	7,503,395.97 €	6,625,426.93 €	-877,969.05 €

Table 5.12, Cost Comparison between Base Case & Optimum Scenario

Before attempting to reach any conclusions concerning the above table the elements of this table will be explained. Table 5.12 shows the individual costs that constitute the total cost of the European Bulk Distribution Network for the Base Case and for the Optimum scenario and the difference between them. The Base Case is the current operations of the Company.

Trunking costs, as explained previously, are the costs incurred when transporting packed pigment from the factories to the filling stations. Handling costs, as explained previously, are the costs incurred at the filling stations when the pigment is received, stored, handled in the filling station and when the pigment is loaded into tankers for the delivery to the customers. Tanker costs, as explained previously, are the costs incurred when the pigment is delivered to the customers using tankers. Included in this cost are the leasing of the tankers, the running costs etc. Lastly, the German Road

Tax, as explained previously, is an extra tax imposed by the German Government to all HGV's travelling through the country.

Taking these costs in turn as they appear in the table there are numerous things to note. It can be seen that in the Optimum scenario there is a 6.75% increase in the trunking costs compared to the Base Case. A slight increase was expected due to the fact that the filling station locations in the Optimum scenario are further away from the factories when compared to the filling station locations in the Base Case. This increased distance of the filling stations in regards to the factories mean that the trunking distances also increase, and since the costs are analogue to the distances, the costs also increase.

Next in turn are the handling costs. The handling costs given to us by the hauliers for the filling stations vary between 4 and 21 €/tonne handled with an average of €12, 6/tonne. The slight decrease that is observed in table 5.10 is attributed to the variation of costs between filling stations. That is to say that because less pigment is going through filling stations that are more expensive than others – and consecutively more pigment is going through less expensive ones – this 0.01% decrease is recorded as compared between the Base Case and the Optimum scenario.

The most interesting and valuable element of table 5.12 is the tanker costs element. From table 5.12 we can see that the tanker costs have significantly decreased. More specifically a 32.5% reduction in cost, as compared to the Base Case, has been realised. A big reduction in costs has been expected since the model was aimed to reduce the tanker travel distances, which were the most costly activity of the European Bulk Delivery Network. Table 5.9 illustrates the reduction in tanker travel distances in Km.

The next element in table 5.12 is the German Road Tax. As explained previously this German Road Tax is a fixed tax imposed by the German government to every HGV travelling through Germany. It can be seen from table 5.12 that there is a significant reduction of this tax in the optimum scenario. This 48.2% reduction as compared to the Base Case is, naturally, due to the reduction of kilometres travelled by both primary transport and tankers through Germany.

The last element in table 5.12 is the total cost of the Base Case and of the optimum scenario as well as the sum of the differences as per element in the table. It can be seen that there has been an overall saving of about 12% in the optimum scenario. This 12% cost saving can be translated in € saved per tonne delivered. For the whole of the European bulk distribution network of the company this 12% cost saving equates to €7.7 saved per tonne delivered.

There is a special point that must be raised at this point. At the UK and Nordics clusters the annual demand is about 35.5 thousand tonnes which is a great part of the total annual demand of all of the Company's customers. As it can be seen from tables 5.9, 4.10 there is a minute change in cost between the base case and the optimum scenario. As such it would be wise to calculate the savings per tonne disregarding the tonnage served from these two filling stations and their respective costs. By doing so it can be seen that the saving is €10 per tonne delivered.

6 Proposed Solution

In the previous chapter we have seen the result that the mathematical model yielded and the savings that could be realised if the optimum scenario would be implemented. In this chapter the changes to the optimum scenario will be presented refined through the filters of reality. The main analysis is shown in chapter 5 as the optimum scenario that the model yielded. In many cases the results shown in the optimum scenario, for a number of reasons, can't be implemented. It could be the case that the throughput of a certain filling station could not justify the presence of that filling station, or it could be the case that the cost of change is too great to go through the change and the cost saving of the change can not justify the change. In this chapter the feasible solution will be presented and a cost comparison will be made at the end of this chapter between the feasible scenario and the base case.

6.1 Further Analysis

As it is shown in figure 3.1, the methodology flowchart, different scenarios were constructed and analysed in order to come up with the final feasible scenario. Every location that the model predicted was questioned by the management of the Company and different solutions were generated.

The analysis performed by the author was concerned only with the transportation costs with regards to various locations for filling stations. The costs of building a filling station, or moving one, were not provided by the Company and as such this cost of change is not part of the analysis. The Company reviewed the transportation and handling costs provided from this analysis and decided as to which location was to be chosen.

In most cases the hauliers and the Company itself, had proposed locations for filling stations that were in close proximity to the optimum locations. These locations were

taken into account and the cost of using these locations was determined. Having the analysis complete the locations were further assessed and a location was decided on. More specifically the locations of the FS in the Base Case were put side by side with the locations of the FS in the optimum scenario. If the proposed location was near the current FS then the current was used in stead of the proposed one. This was due to the fact that moving a FS a few Km to another location makes a very small difference in the overall cost. Because the difference in cost is so small, the cost of moving the FS is not justifiable.

Having conducted the analysis for numerous locations for filling stations the Company decided on the final feasible locations, and these are going to be presented hereafter. This part of the analysis is presented in appendix 8.

6.2 Feasible Number and Location of Filling Stations

The feasible number and location of the filling stations, as opposed to the optimum, are presented hereafter. The feasible scenario yielded 13 filling stations which in turn mean 13 clusters. Some filling stations that were determined by the model are being consolidated into one filling station and other filling stations have been selected due to cost implications or customer growth. The layout of the feasible scenario will follow the layout of the optimum scenario for ease of comprehension.

6.2.1 Customer Clusters and Location of Filling Stations

Few or none of the locations of the filling stations proposed by the model will be kept as filling stations for the feasible scenario. Other locations closer to the optimum from the current scenario are being selected. The reasons behind these selections are many and diverse. In each case a comparison between the feasible and the optimum scenarios will be presented.

6.2.1.1 Spanish and Portuguese Clusters

In the Iberian Peninsula, the four clusters that were shown by the model still exist unaltered. In each cluster though, the location of the filling station has been changed. Figure 6.1 shows the feasible four clusters in the Iberian Peninsula with the new locations of the filling stations.

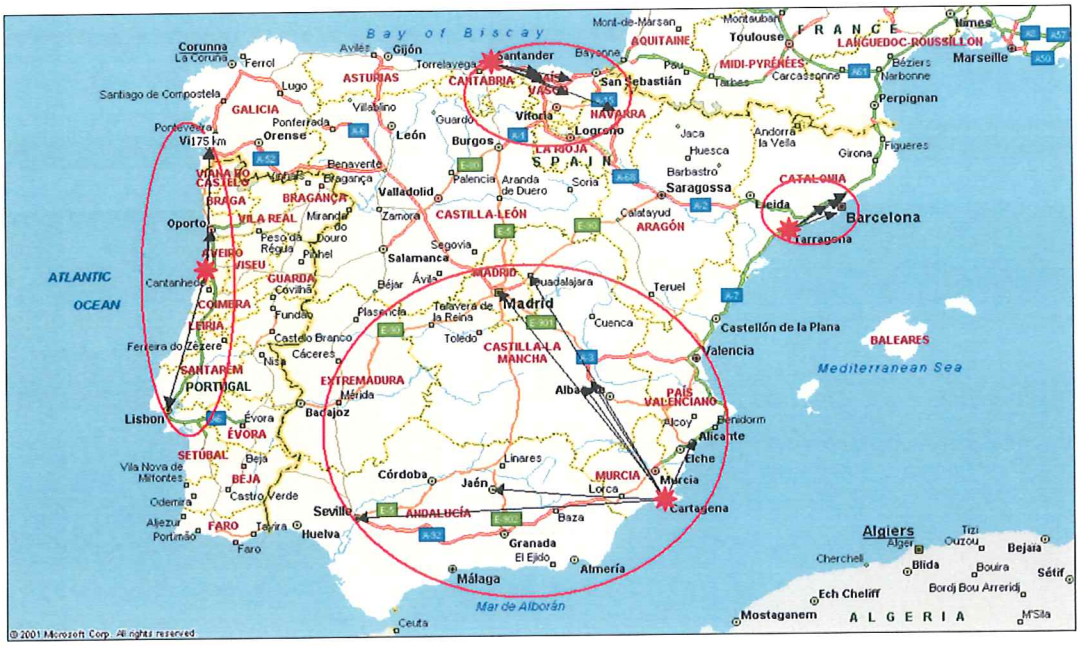


Figure 6.1 Map showing the feasible clusters and FS locations in the Iberian Peninsula

In the north Spanish cluster the filling station that was in Huarte-Araquil near Pamplona, has been changed for the filling station that was used for the whole of the Iberian customers in Santander. This was done since the difference in cost and Kilometres travelled is not great and because the Santander filling station already exists. In the east Spanish cluster the filling station in the outskirts of the city of Barcelona has been changed for a filling station in the city of Tarragona. This location – Tarragona – was proposed to the company by the haulier as a location to build a filling station. In the south Spanish cluster the filling station in La Matanza, in the province of Albacete has been changed for a filling station in the city of Cartagena. Once more this location was proposed to the company by the hauliers a

possible site for a filling station. Lastly the filling station in the Portuguese cluster that was in Caniceira has been changed for a filling station in Aveiro. This last change in filling stations in the Portuguese cluster will have the least effect on the outcome of the costs because the optimum location is just a few Kilometres away from Aveiro. Aveiro was also proposed to the company as a filling station by the haulier.

6.2.1.2 Italian Clusters

In Italy the three filling stations that were determined by the model are substituted by two filling stations. In the optimum scenario there were two filling stations in the North of Italy and one filling station in the south of Italy. The two North Italian filling stations were substituted for one North Italian filling station situated in the city of Novara, just west of Milan.



Figure 6.2 Map showing the feasible clusters and FS locations in Italy

After consulting with the Company's managers it was decided to use the location proposed by the haulier, in Novara. This decision was derived by the fact that the volume going through these filling stations could not justify the existence of both. More specifically, through the filling station near Padova, the annual throughput was around 780 tonnes, and through the filling station near Milan the annual throughput was about 9,000 tonnes.

It must be said at this point that a threshold figure of tonnage that would justify the existence of a filling station was not disclosed but he Company nor was the actual cost of raising a filling station. The filling station proposed by the model near Padova, according to the management, was not a viable solution because of the low volume that it would handle. The decision concerning the North of Italy was that the Company would have a single filling station serving the customers in that area. Novara was chosen as a location for a filling station after consultation with the haulier company that operates in this area. An initial thought for a filling station was the city of Cremona, which is much closer to the optimum location for the whole of the North Italian customers. This idea was abandoned when the haulier provided us with local knowledge and illustrated that Novara was the best solution. The south Italian filling station as determined by the model was substituted for the existing Italian filling station in Grosseto, which used to serve the whole of the Italian Bulk customers. Figure 6.2 shows the feasible clusters and filling stations in Italy.

6.2.1.3 German Clusters

There are two clusters formed in the Central European area. The German cluster and the Belgian cluster. The German cluster incorporates all of the customers situated in Germany and the Belgian cluster is comprised by a single customer, the biggest customer of the company. The filling station selected for the German cluster is the existing filling station in Wesel. This location was decided because the company already has the filling station there and the implications for change are great. Also the

optimum location for a filling station as determined by the model is a few Kilometres from Wesel, and as such the cost implications are again not great.



Figure 6.3 Map showing the feasible clusters in Germany

The second cluster in the Central European area is the Belgian Cluster. This cluster was decided because of the sheer volume of the demand of the Belgian customer. There were thoughts from the company to introduce a filling station in that area to serve this customer in order to reduce costs. From the analysis that is explained in section 6.1, it was shown that introducing a filling station very near to this customer the cost would reduce greatly in spite of having two instead of one filling station. Figure 6.3 shows the German filling stations on the map.

6.2.1.4 French Cluster

In the French cluster, the Netherlands customers were added, and the resulting feasible French cluster is in essence the optimum French and optimum Netherlands clusters together. The filling station of this cluster is the original Calais filling station

in the manufacturing plant. The Netherlands cluster was incorporated into the French cluster because the low volume in the Netherlands did not justify the introduction of a filling station. Figure 6.4 illustrates the French feasible cluster on the map.

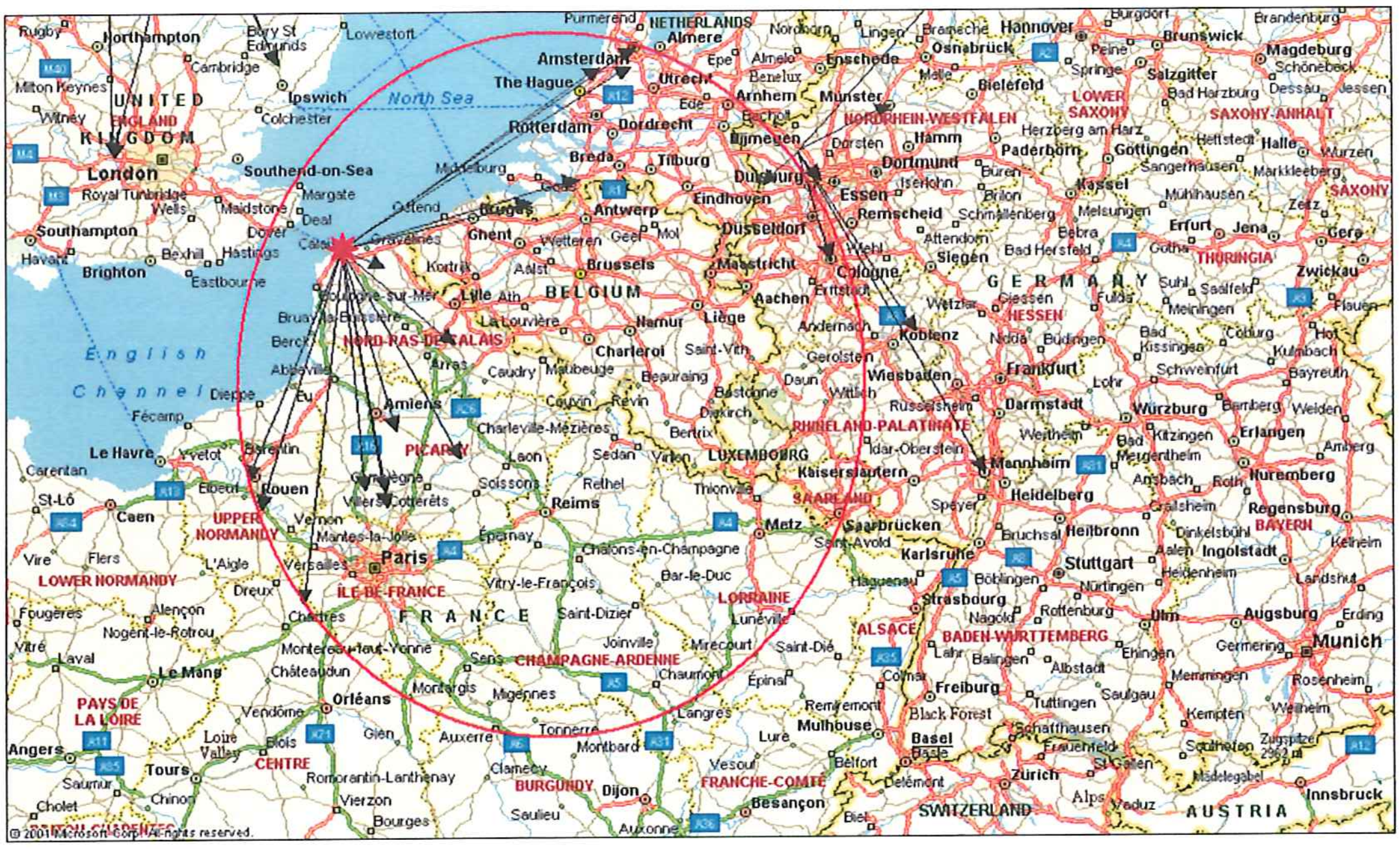


Figure 6.4 Map showing the feasible cluster in France

The Calais filling station was chosen to be the filling station for this cluster because not only it is an existing filling station but this filling station has the ability to load tankers with pigment straight out of production. An additional customer from the Nordics cluster was added to the French cluster. Flugger in Kolding was decided to be served from Calais after an analysis that showed that serving this customer from Calais was cheaper. This customer is not shown in figure 6.4 above but an explanation of this decision is given in the next section.

6.2.1.5 UK Cluster and Nordics Clusters

The UK cluster was decided to be left unchanged. That is to say that the existing filling stations in the two manufacturing plants at Greatham and Grimsby were kept.

It might be recalled that at these two factories and at the Calais factory there are facilities to load tankers straight from production. These sites were thus called filling stations because of that attribute. Since the UK customers are served from the two UK sites and these sites have this ability the decision to have the UK cluster remain unaltered was reached.

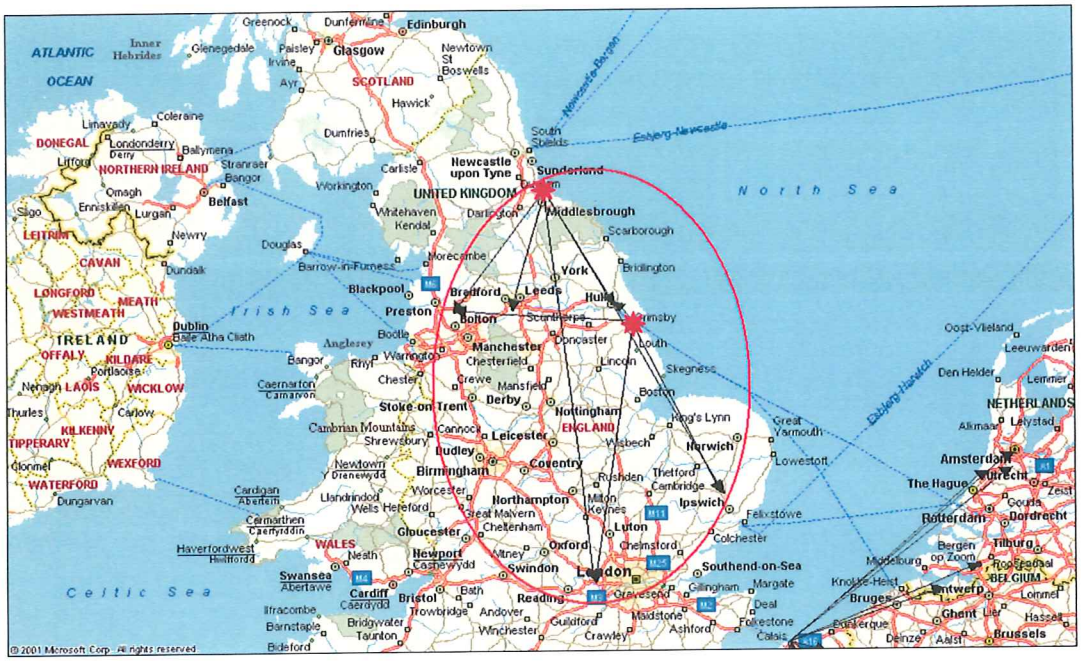


Figure 6.5, Map showing the UK feasible cluster

It was clear to the author that the management of the Company had no intention of changing the UK configuration to the least. There were several reasons behind this decision. The pigment that served the UK market comes from the UK production sites. These sites, as aforementioned, have the ability to fill tankers directly from production keeping handling costs to a minimum; 4€ and 6€ per tonne handled at each site as shown in appendix 6. Installing new filling stations would increase the handling costs because of the double handling at the sites and at the filling stations. There was also the issue of capital investment to install these new filling stations. The cost of all of these changes was too great proportionally to the cost savings that would have been realised with these changes. This information was also known by the hauliers and as such the apparent costs for the proposed journeys that were given to

the author were the same as the costs given by the hauliers for the existing journeys. For these above reasons no further analysis was made and the UK cluster remained unaltered. Figure 6.5 illustrates the UK feasible cluster.

The Nordics clusters were decided to remain unaltered for the exact same reasons that the UK cluster remained the same, with the exception of one customer in Kolding. This customer was decided to be served from Calais since this option was cheaper. As shown in the table below the cost of transporting 1 tonne of pigment from the factory to the customer is cheaper if this customer is served from Calais.
Table 6.1 below is an extract from the data provided in the appendix. In table 6.1 it can be seen that the tanker cost for transporting the pigment is much higher but the overall cost reduces. This reduction, as it seen, comes from the reduced Primary and handling costs.

Served from Gothenburg	**Served from Calais**
Primary cost	
Base Case	Feasible
65.60 €	25.40 €
Handling cost	
Base Case	Feasible
17.00 €	9.00 €
Tanker cost	
Base Case	Feasible
48.15 €	88.59 €
Euros per tonne	
130.75 €	**122.99 €**

Table 6.1, Cost analysis for customer in Kolding

The Turku cluster has one customer and thus this is the optimum position for a filling station provided a closer location can be found. In the Gothenburg (Kungsbacka) cluster, as it was mentioned in paragraph 5.2.1.7, the optimum location for a filling station is very close to the existing filling station and changing to the optimum could not be justified since there is no cost saving in the optimum case.

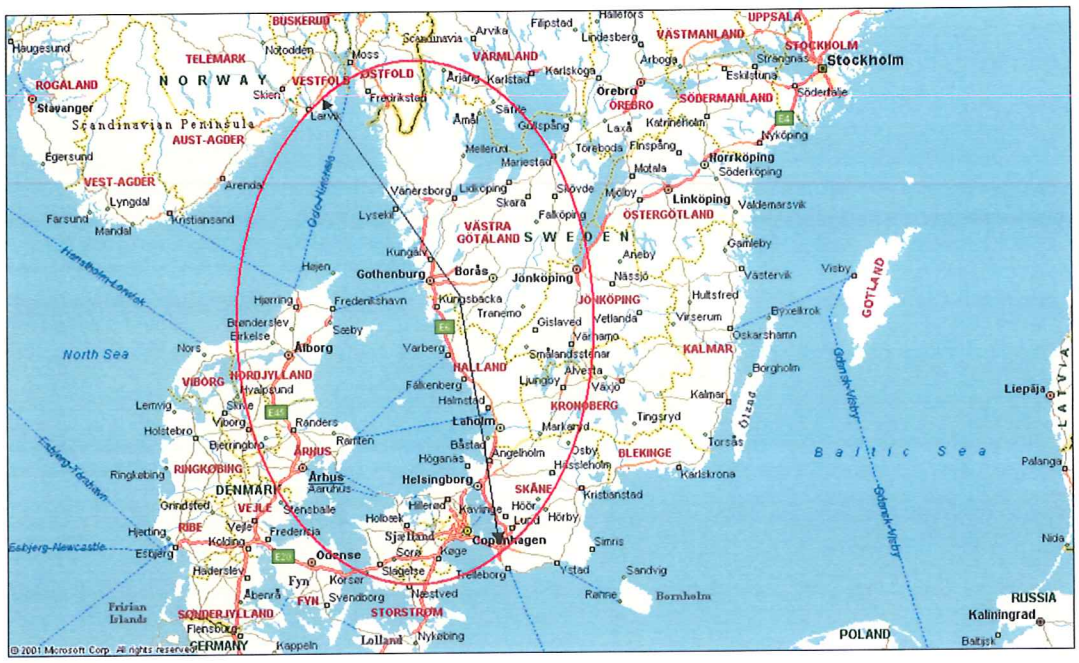


Figure 6.6, Map showing the feasible Gothenburg (Kungsbacka) cluster

Figure 6.6 illustrates the Gothenburg (Kungsbacka) cluster on the map. The Turku cluster is not illustrated since there is no change associated with it.

6.2.2 Cost of Feasible Scenario

The total cost of the feasible scenario was once more calculated in the same manner as the total cost for the optimum scenario. The same methodology for calculating the costs is used throughout the analysis to ensure a valid basis for comparison between each scenario. The costs presented in table 6.2 below, are the total cost for each cluster. The figures for the cost incorporate the trunking costs, handling costs and the tanker costs. Table 6.2 follows the same illustrative philosophy as table 5.9 which illustrates the total cost of the optimum scenario. The data behind table 6.2 are shown in appendix 8.

Cluster	Cost
Novara	617,256.42 €
Grosseto	126,017.01 €
Santander	523,067.29 €
Taragona	291,464.96 €
Cartagena	301,416.79 €
Aveiro	235,714.63 €
GM/GY	974,911.22 €
Turku	153,367.50 €
Kungsbacka	116,224.75 €
Calais	816,249.58 €
Liege	1,015,157.41 €
Wesel	1,638,872.45 €
German Road Tax	11,586.39 €
Total Cost	**6,821,306.39 €**

Table 6.2, Total cost of feasible scenario

6.3 Comparison between Current and Feasible Scenario

This feasible scenario is a pragmatic view of the optimum scenario, and as such the aims of this analysis have not changed. The minimisation of tanker travel distances is still of prime importance. Since the filling stations proposed in this scenario are not the optimum however, it is only a logical outcome that the tanker travel distances are going to be increased. Calculations of these new tanker travel distances have shown a slight increase in the total cost of the operations. Table 6.3 shows the tanker travel distances in the base case, the optimum and the feasible scenarios.

	Base Case	Feasible	Optimum
Kilometres Travelled	19,393.1	9,825.8	6,412.0

Table 6.3, Kilometres travelled by the tankers in the three scenarios

These tanker travel distances have been calculated with the use of the Microsoft® AutoRoute 2003 software package. The distances between the customers, Filling stations and factories were recorded and the total number of Kilometres travelled was

calculated with the use of the number of journeys per customer, as explained in more detail in paragraph 5.2.2. All of the data concerning the tanker travel distances are shown in appendices 7a and 7b.

It can be seen from the above table that there was an increase in tanker kilometres travelled but when compared to the base case the difference is great. Another implication that the feasible scenario has on the costs is that of the trunking costs. As it can be seen, most of the filling stations in the feasible scenario are the existing ones the company uses in its current operations. Thus it can be expected that the trunking costs will have changed, and in fact reduced as compared to the optimum scenario. For the same reason, that is the locations of the filling stations, the tanker costs will have increased since the Km travelled are increased. Table 6.4 shows the breakdown of the total costs of the feasible scenario. The breakdown, as in table 5.12 for the optimum scenario, is done according to the three activities comprising the supply of pigment in bulk to customers; the trunking cost, handling cost and the tanker cost.

	Base Case	Optimum Scenario	Feasible Scenario	Difference Optimum/BC	Difference Feasible/BC
Trunking Costs	2,881,194.15 €	3,075,612.85 €	2,884,925.94 €	194,418.71 €	3,731.79 €
Handling costs	1,352,003.09 €	1,351,869.33 €	1,347,549.33 €	-133.76 €	- 4,453.76 €
Tanker Costs	3,226,545.93 €	2,175,325.41 €	2,577,244.74 €	-1,051,220.52 €	- 649,301.19
German Road tax	43,652.81 €	22,619.34 €	11,586.39 €	-21,033.48 €	- 32,066.42 €
Total Costs	7,503,395.97 €	6,625,426.93 €	6,821,306.39 €	- 877,969.05 €	- 682,089.58 €

Table 6.4, Cost Comparison between Base case, Optimum and Feasible scenarios

The implications of the changes described throughout this chapter can be summarised and illustrated in the above table.

Firstly the implications on the trunking costs are shown. It can be seen that the trunking costs of the feasible scenario when compared to the base case have increased slightly by 3,731.79 € but when compared to the optimum scenario they have decreased by around 194 thousand euros. This decrease in trunking costs can be attributed to the fact that trunking packed pigment to the selected filling stations in

the feasible scenario is cheaper that transporting packed pigment to the filling stations of the optimum scenario.

In table 6.4, it can also be seen that there is a slight reduction on the handling costs of the feasible scenario as compared to the optimum scenario. This can be attributed to the fact that the filling stations used in this scenario are cheaper to run than the proposed ones in the optimum scenario, thus when more volume goes through the cheaper filling stations the handling costs reduce.

As expected the tanker costs in the feasible scenario have increased as compared to the optimum but still remain a great saving as compared to the base case. This increase in tanker costs is due to the increase of the travel distances of the tankers, as illustrated in table 6.3.

As in the optimum scenario the greatest saving that is realised is in the European continent. That is the whole of the company's operations excluding the UK and the Nordics clusters, which don't change a great deal. The corresponding saving per tonne in the European continent in the feasible scenario is 7.3 €/tonne. If the equivalent saving of the optimum scenario is recalled from the previous chapter it can be seen that there is approximately a 3 euros difference in the savings per tonne, since the equivalent saving in the optimum scenario was 10 €/t.

The overall saving per tonne of the feasible scenario, when the whole of the operations of company are being taken under consideration is about 5.7 €/t. When this figure is compared to the saving of the optimum scenario, it can be seen that the difference is less than 2 euros per tonne.

7 Conclusions

This last chapter is concerned with summarising the work done in this project and drawing some key learning points and logical conclusions from this work. Also a critique of the project is going to be made illustrating whether or not the methods used, the overall approach and the analysis used were successful.

7.1 The Project

This project dealt with the optimisation of the European Bulk Delivery Network of a Chemical Company based in the UK. Due to a shift of the customers needs from receiving pigment in bulk form rather than in packed form the Company had to reassess its delivery network strategy. Pigment can be delivered to customers in bulk by the means of belly tankers. Using belly tankers to deliver pigment in bulk is very costly so the primary objective of this project was to find the optimum locations for filling stations throughout the European continent in order to minimise the tanker travel distances. The secondary objective of this project was to reduce the cost of the European Bulk Delivery Network.

In order to meet these objectives, the following were done. Firstly, the current operations – the Base Case – and the cost of the base case were established. Secondly the optimum locations for the filling stations were found with the use of a mathematical model, the Centre of Gravity method. This optimum scenario, with the optimum locations for filling stations, was analysed and the total cost and other parameters like kilometres travelled were found. The next step of this project was, with the initiatives of the Company managers and the hauliers, to generate the feasible scenarios. These feasible scenarios were modifications of the optimum scenario to allow it to be implemented. The last step was to compare these scenarios to the base case and realise the cost savings for each.

7.2 Summary of Conclusions

In this paragraph, a summary of all the conclusions of this project are going to be presented.

The initial mapping of the base case revealed the total cost of operations and the cost per filling station. These costs are going to be the basis for comparison with the other scenarios since these are the current costs that the Company is incurring. Table 7.1 below, illustrates these costs.

Cluster	Cost
Grosseto	933,085.89 €
Santander	1,493,993.59 €
GM/GY	974,911.22 €
Turku	153,367.50 €
Kungsbacka	186,831.00 €
Calais	2,078,587.76 €
Wesel	1,638,966.20 €
German Road Tax	43,652.81 €
Total Cost	**7,503,395.97 €**

Table 7.1, Total cost of Base Case segmented by FS including German Road Tax

The analysis performed in the optimum scenario revealed some very interesting points. It is important to mention the very large reduction in tanker travel distances as compared to the base case. By installing filling stations in the optimum locations in regards to the customers the tanker travel distances were reduced by 67%. To balance this vast reduction in travel distances, it can also be seen that there was an increase in the trunking costs. The increase in trunking costs is attributed to the fact that the filling stations now are moved further away from the factories and as such the trunking distances have increased. The overall cost difference between the base case and the optimum scenario is in the region of 30%, to translate this percentage figure, the cost difference between the optimum scenario and the base case is 877,969.05 €.

	Optimum Scenario	Base Case	Difference Optimum/BC
Trunking Costs	3,075,612.85 €	2,881,194.15 €	194,418.71 €
Handling costs	1,351,869.33 €	1,352,003.09 €	-133.76 €
Tanker Costs	2,175,325.41 €	3,226,545.93 €	-1,051,220.52 €
German Road tax	22,619.34 €	43,652.81 €	-21,033.48 €
Total Costs	**6,625,426.93 €**	**7,503,395.97 €**	- 877,969.05 €

Table 7.2, Cost comparison between BC & Optimum broken down by activity

Braking down this total cost saving to the three distinct activities, as in table 7.2, it can be seen that between the optimum scenario and the Base case there is an increase of 194,418.71 € in the trunking costs and a decrease in tanker costs of 1,051,220.52 €. There are another two elements of the cost that have changed; the handling costs and the cost of the German Road Tax. The slight decrease of the handling costs is attributed to the fact that volume now goes through filling stations that cost less to the Company to operate than others. The decrease in the German Road Tax is due to the fact that fewer kilometres are travelled through Germany by both tankers and trucks in the optimum scenario.

The above cost savings realised with the optimum scenario can be translated into euros saved per tonne delivered. Taking account the whole of the Company's operations the saving amounts to 7.7 €/t. It can be seen that in the UK and Nordics clusters there is an insignificant change in cost and great piece of the annual volume delivered, so it would be wise to calculate the euros saved per tonne delivered excluding the tonnage in these two clusters and their cost. This figure comes up to 10 €/t.

In the following paragraph, the conclusions reached from the construction and analysis of the feasible scenario will be presented. As it can also be seen from table 7.3 later in the text, there is a slight increase in trunking costs in the feasible scenario as compared to the base case, but a dramatic decrease as compared to the optimum scenario. These changes were expected and are due to the fact that many filling stations have been moved closer to the factories thus reducing the trunking distances. This has created an action-reaction effect to the tanker costs in the feasible scenario.

As the filling stations have been moved closer to the factories, they are therefore further away from the customers, increasing the tanker travel distances. That is why there is an increase in the tanker costs as compared to the optimum scenario, but there is still a significant reduction in costs as compared to the base case.

	Base Case	Optimum Scenario	Feasible Scenario	Difference Optimum/BC	Difference Feasible/BC
Trunking Costs	2,881,194.15 €	3,075,612.85 €	2,884,925.94 €	194,418.71 €	3,731.79 €
Handling costs	1,352,003.09 €	1,351,869.33 €	1,347,549.33 €	-133.76 €	- 4,453.76 €
Tanker Costs	3,226,545.93 €	2,175,325.41 €	2,577,244.74 €	-1,051,220.52 €	- 649,301.19
German Road tax	43,652.81 €	22,619.34 €	11,586.39 €	-21,033.48 €	- 32,066.42 €
Total Costs	7,503,395.97 €	6,625,426.93 €	6,821,306.39 €	- 877,969.05 €	- 682,089.58 €

Table 7.3, Cost Comparison between Base case, Optimum and Feasible scenarios

As aforementioned, there is an increase of the trunking costs of the feasible scenario of 3,731.79€ as compared to the Base Case. The trunking costs have reduced as compared to the Base Case but have increased as compared to the optimum scenario. Namely the tanker costs have decreased by 649,301.19€ as compared to the base case but increased by around 400,000€ as compared to the optimum scenario.

It can also be seen from table 7.3 that there is a great reduction in handling costs in the feasible scenario as compared to both the Base case and the optimum scenario. The reason behind this decrease in handling costs is that fewer tonnes of pigment are handled at expensive filling stations. Last but no least comes the German Road Tax. It can be seen that this has also reduced in the feasible scenario as compared to both the Base case and the optimum. The reason behind this reduction is purely because of the location of the filling stations. With the arrangement of the feasible scenario the kilometres travelled on German soil are less than in both the previous scenarios.

7.3 Key issues and Learning points

The key issues and learning points of this project have been identified throughout the course of the analysis and the discussion in the above section and have played a major role in the formation of the end result. These key issues are going to be summarised in this section illustrating their role towards the end result.

The first issue that was noted was the importance of trade-offs. It has been seen throughout the project that trade-offs are necessary to reach a golden cut in terms of the cost of the European bulk delivery network. The further away from a factory a filling station is installed, the closer it will be to the customers thus reducing the tanker cost associated with these customers. At the same time, because the filling station is far away from the factory, the trunking costs will increase. A non realistic approach would be to install filling stations next to each of the customers in order to reduce the tanker cost to zero. That would require a large investment in filling stations that would operate very inefficiently due to the low volume per filling station and result in enormous trunking costs. Another unrealistic approach would be to dismiss the idea of filling stations and use tankers directly from the factory to the customers. With this approach the Company would be free of trunking costs and the costs associated with filling stations, but the tankers costs would be enormous. It is evident that that a trade-off must be made between these two distances – between the FS and the factory and between the FS and the customers – and the number of filling stations. This whole project relies on this principle since the filling stations were moved closer to the customers in order to reduce the tanker costs. As it seen though, this had an adverse effect on the trunking costs. These trade-offs can be seen throughout the project and in the conclusive table 7.3 in the previous section.

Another learning point was that the optimum result yielded by a mathematical model is not always a feasible option. The mathematical model used, as with the plethora of models, has some limitations. Although these will be presented and discussed in a later section - critique section - one limitation should be mentioned at this point to aid the discussion. This is that the model does not distinguish between different areas or

terrain. This means that the model could calculate the optimum location to be on water or somewhere that a filling station can not be build. Or that the location calculated does not take into account special features of each area like traffic or road conditions. For example the location for the filling station selected for northern Italy was Novara for these exact reasons.

Another issue that came across in this project was the need to accommodate for practical requirements of the management. In many cases across the project, and regardless of the outcome of any analysis the management insisted on various solutions. As aforementioned there are many examples of these throughout the thesis. The two most representative examples of the need to accommodate for the practical requirements of the management are the decisions to leave the UK and the Nordics clusters untouched. As seen from section 6.2.1.5 these two clusters in the feasible scenario have remained as they were in the Base Case. Possible reasons behind these decisions may be interactions with future Company plans or even Company politics.

7.4 Recommendations

In this section some recommendations to the Company are going to be made concerning the implementation of the feasible scenario. From the conclusions of this thesis a sequence of implementation can be devised in accordance to the cost savings realised at each region, as defined by the clusters used throughout this thesis. These recommendations will limit themselves to the first three clusters, since these three constitute the bulk of the cost savings realised.

The first step in implementing this project would be to install the new filling station in Belgium in order to serve the Belgian customer. Installing the filling station in Belgium would realise a cost saving of 309,222.22 €. The next step would be to implement the changes proposed for the Italian clusters. These changes would realise a cost saving of 189,812.46 €. The third step of the implementation project would be

to change the Iberian Peninsula cluster. By implementing the proposed changes the Company would realise a cost saving of 142,329.92 €. The sequence of the remaining steps of the implementation project is less significant since the cost savings of the remaining clusters are much less than each of the aforementioned ones.

It is also recommended that the company reassesses its European Bulk Distribution strategy in the future taking into account possible changes in demand, cost, or the acquisition or loss of new customers. A discussion of a sensitivity analysis will be attempted in the next section, but it must be stated at this point that since the environment of any market is a dynamic one the Company should constantly adapt to it.

7.5 Critique

In this section a critique of the work done will be attempted. This critique will touch on matters like the limitations of the methods used, a sensitivity analysis, the quality of the data obtained and the possible impact that the inventory holding costs might have on the result.

The centre of gravity method that was used to define the optimum locations of the filling stations throughout the European Bulk Delivery Network of the Company was sufficient to comply with the prime objective of this project. The method took into account the relative distances of the customers and their respective demand and calculated an optimum location for a filling station in each cluster formed. This method was limited by the quality and form of the data provided by the hauliers. Each haulier provided the author with costs in the form of € per journey or € per tonne handled in the case of the filling stations. In order to obtain a cost for the scenarios devised the respective cost for each journey was applied and the total cost was obtained. If the costs were given to the author in the form €/Km travelled for every journey, the total cost of the cluster could have been calculated by the model. In this way the optimum location would be calculated not only in accordance to the

respective distances between the customers and their demand but also with respect to the actual cost of serving these customers. Although this change in the form of the costs would add an extra factor in the mathematical equations of the model, it would provide a more accurate result.

The form that the costs were given to the author was not the only limiting aspect of them. The hauliers provided the costs of the existing journeys but provided very little data concerning the costs for the new proposed journeys and filling stations. Most of the trunking journeys costs were provided by the hauliers, but the more important tanker journey costs were left vague and not at all exact. The final costs used were decided after consulting with both the management and the hauliers. Had the hauliers provided the author with the exact costs for every activity the results would have been much more realistic and accurate.

A principal question that arises is concerned with the sustainability of the proposed European Bulk Delivery Network of the Company. The Company has a specific strategy concerning the bulk delivery market that it is in. That is to be very selective and reluctant as to whom they are going to deliver in bulk. That is because of the great cost incurred with the bulk delivery. It must be reminded at this point that the bulk business of the Company is only a fraction of their total business.

This project was concerned with the strategic location of filling stations throughout the European Bulk Delivery Network of the Company in order to reduce the cost of delivering pigment in bulk to its customers. It was not concerned at any point with the size or the effective throughput of the filling stations although it was mentioned in chapter 4 that the filling stations can fill 4 to 5 tankers a day. Using these figures for the daily tanker filling rate of the filling stations and assuming a 48 week year, the filling capacity of the filling stations vary between 336,960 tonnes per annum, if four tankers are filled each day and 421,200 tonnes per annum, if five tankers are filled each day. It can be seen in both cases that the normal and maximum filling capacity of the filling stations are at least 3 times the total annual volume of the pigment delivered today. As such it is safe to say that the filling station network is capable of delivering pigment even with a doubling of the amount of pigment delivered.

The last point raised in this discussion of the critique of this project, is that of inventory holding costs. As it was agreed with the Company, the inventory holding costs were omitted from any calculations or analysis from the offset of this project.

The total distribution cost of a company, as stated in section 2.1 in the Literature review chapter, is comprised of the warehousing costs, the transport costs and the inventory holding costs. The inventory holding costs can play a significant role in the formation of the delivery strategy of any company. As seen from figure 2.5 in section 2.1.2, as the number of filling stations increases so do the inventory holding costs increase, in an exponential manner. If the inventory holding costs were calculated it could have been the case that the cost of having 13 filling stations throughout Europe would be too great to bare because of the high inventory costs. If that were the case then a trade-off between the tanker costs and the inventory holding costs had to be made. In this case the Company should calculate the extra costs incurred from the inventory holding costs versus the benefits achieved from resituating the filling stations. This could be done by calculating the amount of stock held in each of the filling stations and the amount of stock in transit and comparing it to the benefits that arise from the feasible scenario. This analysis could yield that having 13 filling stations throughout Europe is not an economically viable solution. In order to reach a conclusion and to properly evaluate the outcome, a full scale project should be run incorporating in the analysis presented in this thesis, the inventory holding costs. In such a way a realistic conclusion to the optimisation of the European Bulk Delivery Network could be reached.

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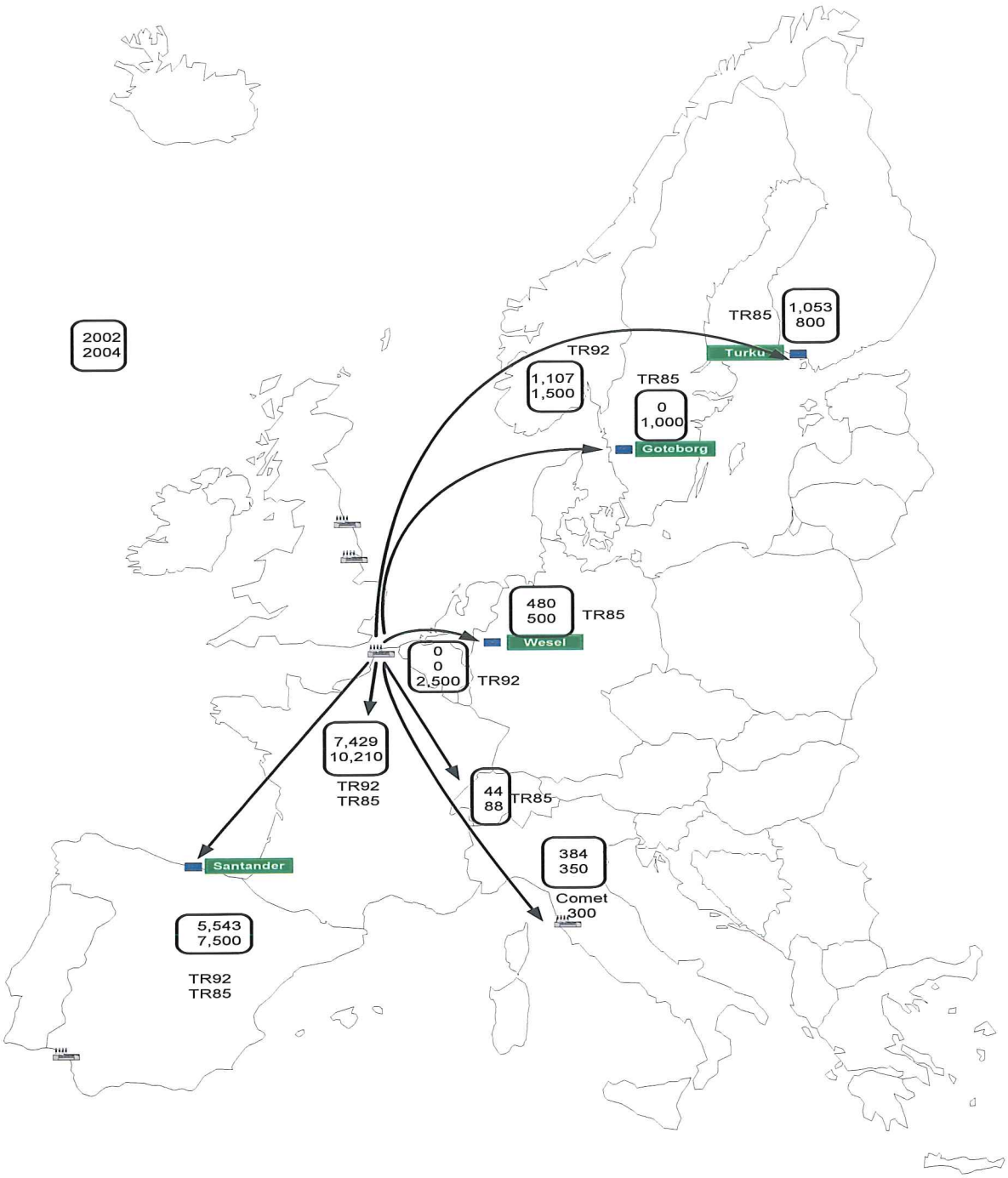
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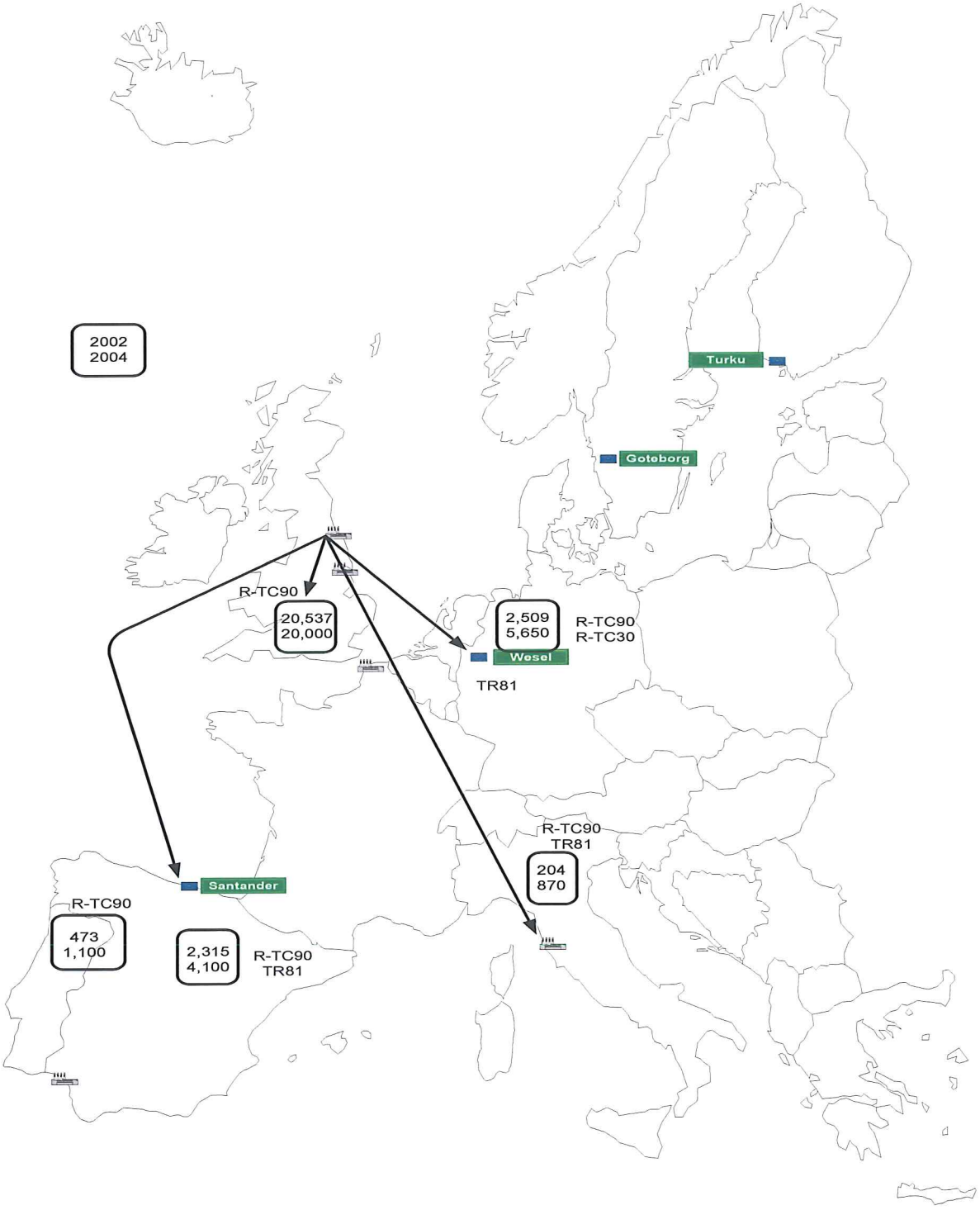
10 Appendices

The Appendices listed hereafter are all of the maps, data and analysis referred to in the text. Due to confidentiality agreement signed by both the Company and the author the data concerning sensitive information about customers and costs from specific hauliers are hidden or altered. An effort has been made to balance the author's obligation towards the Company and the confidentiality agreement and the purpose of these appendices.

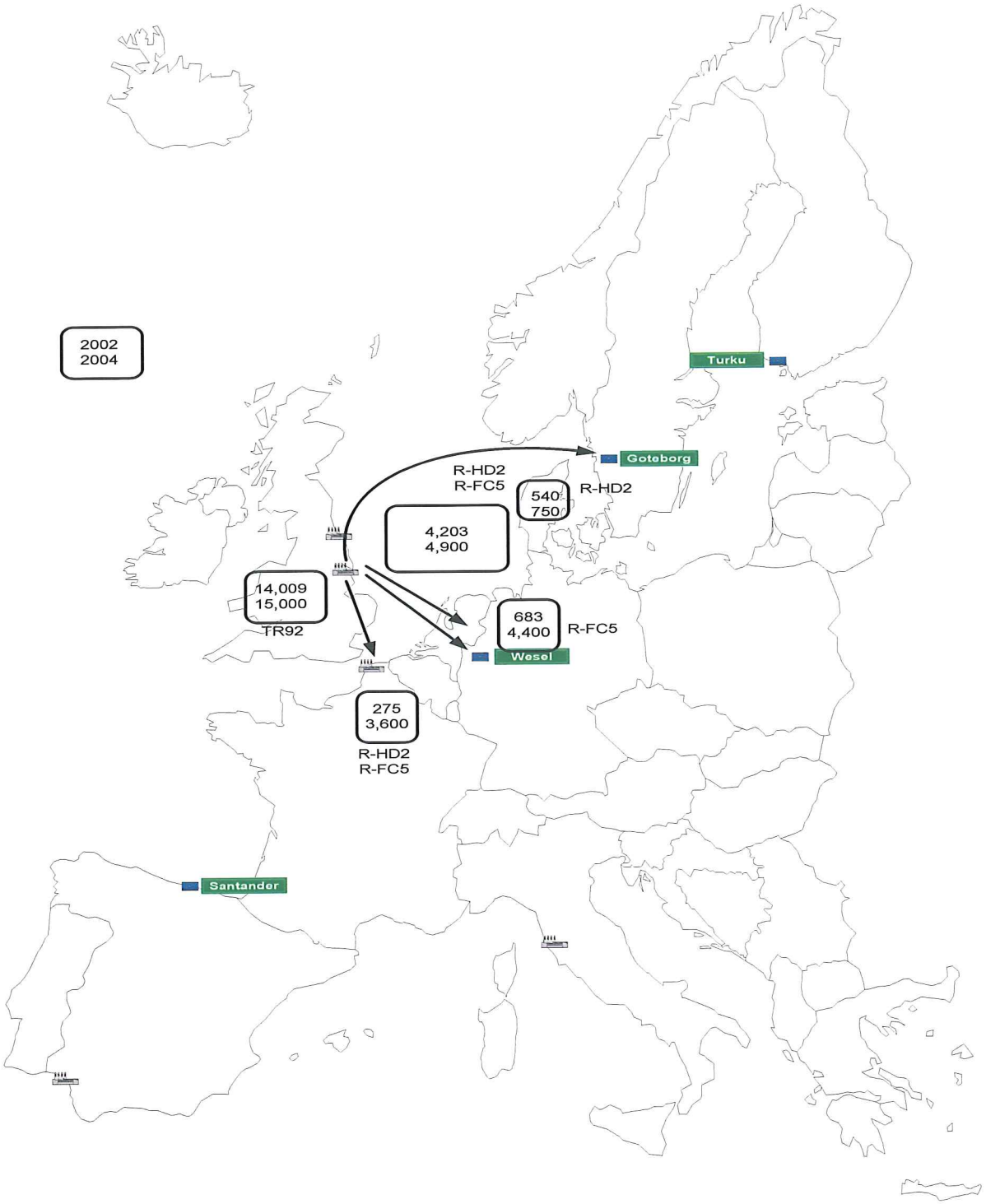
Appendix 1, Calais Manufacturing site Bulk Movements



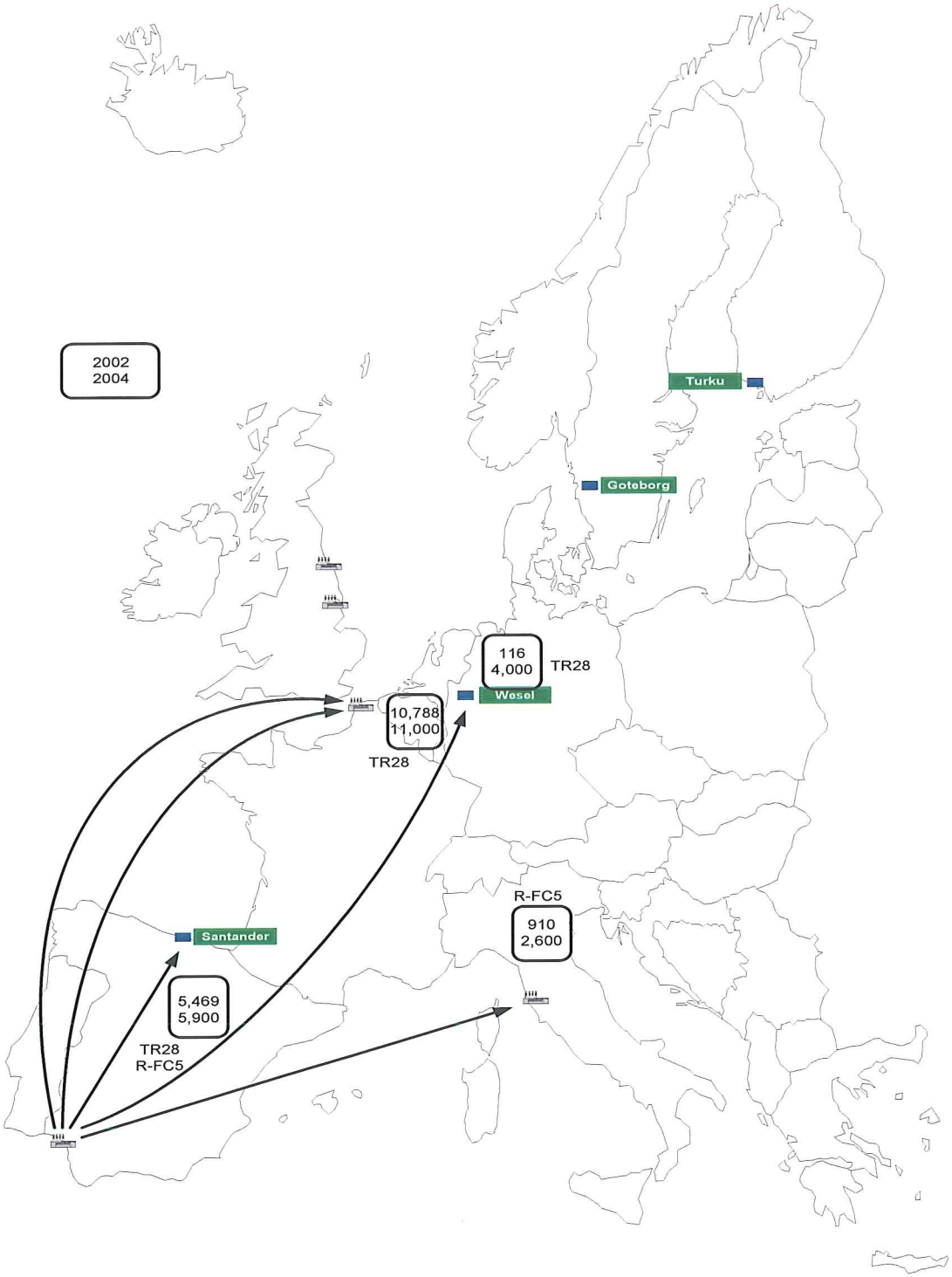
Appendix 2, Greatham Manufacturing site Bulk Movements



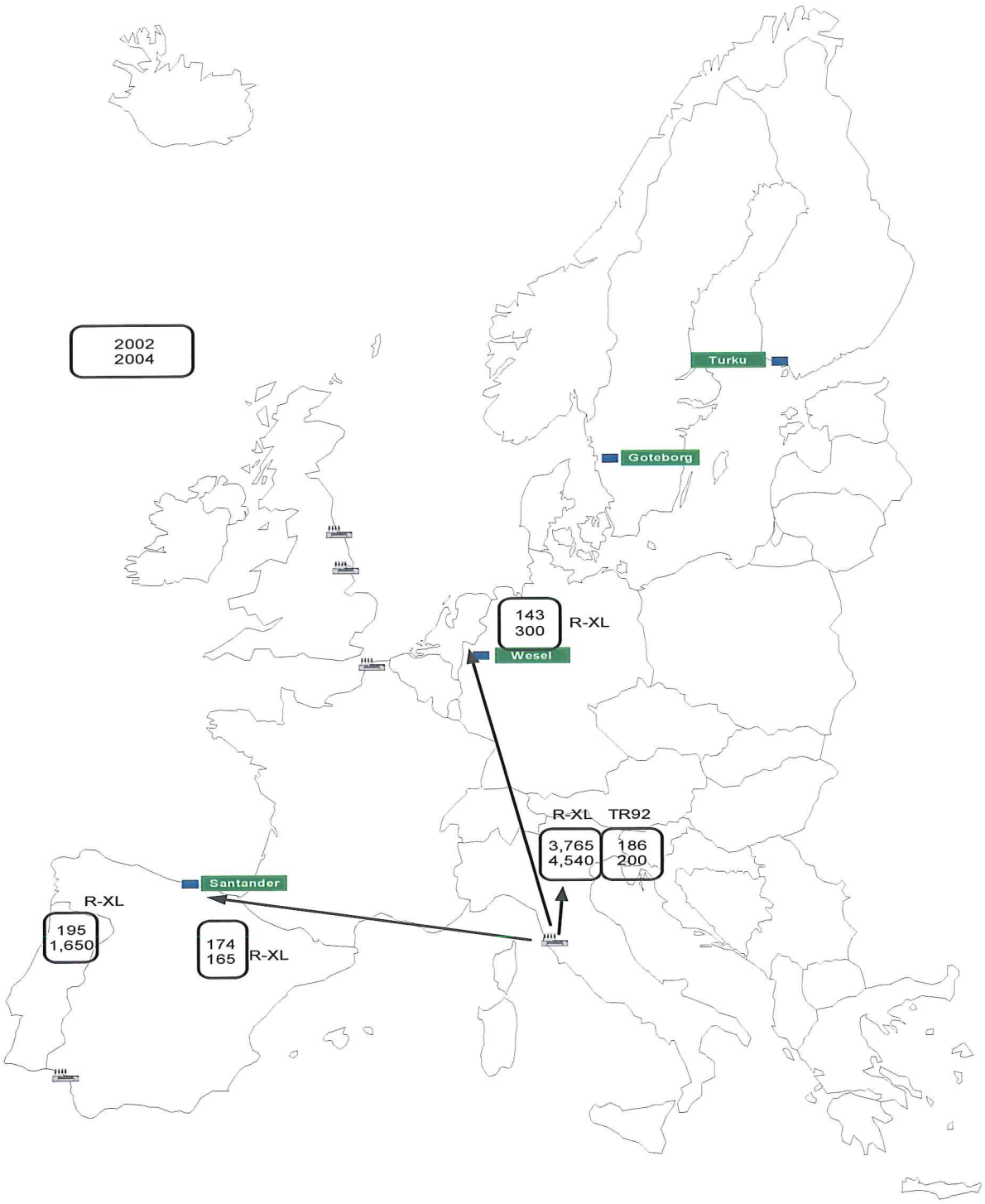
Appendix 3, Grimsby Manufacturing site Bulk Movements



Appendix 4, Huelva Manufacturing site Bulk Movements



Appendix 5, Scarlino Manufacturing site Bulk Movements



Appendix 6

Handling Costs of all the Filling stations under consideration

As it can be seen, the table below shows the handling costs of not only the filling stations discussed in the base case, but also the filling stations considered in the optimum and feasible scenarios. In this way an immediate comparison can be made between the handling costs of the filling stations if needed.

Handling costs in Euros per tonne for every Filling Station Considered

Filling Station	Country	Handling cost per tonne
Huarte-Araquil (Pamplona)	Spain	12.00 €
Santander	Spain	12.00 €
Barcelona	Spain	12.00 €
La Matanza (Albacete)	Spain	12.00 €
Caniceira (Coimbra)	Portugal	12.00 €
Aveiro	Portugal	12.00 €
Grosseto	Italy	14.11 €
Novara	Italy	5.96 €
Briana (Padova)	Italy	14.11 €
Monchengladbach	Germany	21.00 €
Wesel	Germany	21.00 €
Liege	Belgium	21.00 €
Calais	France	9.00 €
Grandvilliers	France	9.00 €
Grimsby	UK	4.00 €
Greatham	UK	6.00 €
Gothenburg	Sweden	17.00 €
Turku	Finland	37.00 €

Appendix 7a

Kilometric Distances of customers from Filling Stations in the Optimum scenario, the proposed scenario and the Base Case

Cluster/ customer	Optimum Distance (Km)	Base Case Distance (Km)	Feasible Distance (Km)	Cluster/ customer	Optimum Distance (Km)	Base Case Distance (Km)	Feasible Distance (Km)
Spain 1	93.0	69.0	69.0	Italy South	151.0	200.0	200.0
Spain 1	85.0	75.9	75.9	Italy South	150.0	115.0	115.0
Spain 1	80.0	81.0	81.0	Italy South	300.0	125.0	125.0
Spain 1	47.0	117.0	117.0	Italy South	300.0	119.0	119.0
Spain 1	40.0	122.0	122.0	Germany	125.0	78.8	198.0
Spain 1	30.5	191.0	191.0	Germany	48.5	28.5	123.0
Spain 2	15.0	524.0	65.4	Germany	48.5	28.5	123.0
Spain 2	9.2	543.0	72.4	Germany	38.0	35.2	103.0
Spain 2	11.6	543.0	87.4	Germany	38.0	35.2	103.0
Spain 2	23.0	543.0	98.5	Germany	43.0	85.0	90.0
Spain 2	23.0	543.0	98.5	Germany	76.0	283.0	0.0
Spain 3	264.0	340.0	391.0	Germany	125.0	162.0	144.0
Spain 3	265.0	324.0	387.0	Germany	233.0	276.0	226.0
Spain 3	87.3	500.0	207.0	Germany	363.0	308.0	441.0
Spain 3	84.6	500.0	205.0	Netherlands	35.0	263.0	35.0
Spain 3	181.0	637.0	247.0	Netherlands	18.0	573.0	18.0
Spain 3	121.0	700.0	0.0	Netherlands	19.0	234.0	19.0
Spain 3	121.0	700.0	0.0	Netherlands	73.0	181.0	73.0
Spain 3	117.0	636.0	102.0	Netherlands	104.0	146.0	104.0
Portugal	183.0	694.0	214.0	France	140.0	34.0	34.0
Portugal	183.0	694.0	214.0	France	116.0	109.0	109.0
Portugal	87.8	476.0	56.7	France	44.5	140.0	140.0
Portugal	210.0	424.0	174.0	France	92.0	181.0	181.0
Italy Milano	11.6	344.0	41.0	France	44.5	180.0	180.0
Italy Milano	16.7	344.0	48.0	France	55.0	194.0	194.0
Italy Milano	13.3	344.0	43.5	France	35.0	179.0	179.0
Italy Milano	122.0	269.0	119.0	France	65.0	183.0	183.0
Italy Milano	37.2	387.0	43.5	France	71.0	202.0	202.0
Italy Milano	193.0	538.0	197.0	France	115.0	264.0	264.0
Italy Briana	38.5	311.0	227.0	France	208.0	345.0	345.0
Italy Briana	18.7	303.0	254.0	Gothenburg	199.0	212.0	212.0
Italy Briana	22.0	334.0	284.0	Gothenburg	214.0	221.0	221.0
Italy Briana	68.0	362.0	330.0	Gothenburg	280.0	274.0	274.0
Italy South	149.0	337.0	337.0	Turku	155.0	155.0	155.0
Italy South	86.0	256.0	256.0				
Total	**3,138.0**	**14,105.9**	**5,455.8**	**Total**	**4,122.0**	**6,149.2**	**5,232.0**

Appendix 7b

Examples of the outcome of the Microsoft AutoRoute ® 2003 software package

In this appendix two examples of the outcome of the Microsoft AutoRoute ® 2003 software package are shown. The first example is the map of the North Spanish (Santander) cluster as discussed in section 6.2.1.1 of the text. It illustrates the filling station with arrows leading to all the customers of that cluster. The second example is the map of the Southern Italian cluster as discussed in section 6.2.1.2 in the text. It illustrates the Proposed filling station in Grosseto serving the Italian Bulk customers in that cluster.

Appendix 7b


Bay of Biscay
Golfo de Vizcaya
Santander
Santoña
Laredo
Castro-Urdiales
Bermeo
Getxo
Portugalete
70.3 km
Bilbao
76.5 km
81.4 km
Gernika
Lekeitio
Ondárroa
Zumaia
Zarautz
San Sebastián
Hendaye
Irún
Biarritz
FRANCE
AQUITAINE
117 km
Elgóibar
Eibar
Durango
Amorebieta
PAÍS VASCO
CANTABRIA
Cantabrian Mountains
Iberian Peninsula
SPAIN
Mondragón
Oñate
122 km
Vitoria
Pamplona
192 km
NAVARRA
Pyrenees
Parque Natural de Urbasa y Andía
Miranda de Ebro
CASTILLA-LEÓN
LA RIOJA
Espacio Natural de los Montes Obare
Medina de Pomar
Puerto de Orduña
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Ligurian Sea
Livorno
121 km
124 km
Pistoia
Prato
Florence
Empoli
Cecina
TUSCANY
Siena
Montepulciano
Piombino
Follonica
Grosseto
Orbetello
Perugia
113 km
UMBRIA
Assisi
Foligno
Spoleto
Terni
Orvieto
Viterbo
LAZIO
Rome
Civitavecchia
MARCHE
Macerata
198 km
Ancona
Adriatic Sea
Pescara
254 km
L'Aquila
ABRUZZI
MOLISE
Campobasso
PUGLIA
Foggia
CAMPANIA
Naples
335 km
Salerno
Tyrrhenian Sea
Mediterranean Sea
CORSICA
FRANCE
Bastia
Ajaccio
Porto-Vecchio
Sardinia
CROATIA
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Appendix 7c

Table showing the demand data of the customers in tonnes per annum

This Table illustrates the bulk demand data of the customers. It can be noted that the names of the customers and the Grade of pigment that they use has been omitted from the table. These figures of demand originate from the Company. It was explained that these figures are historic figures of the demand of the customers from the previous year filtered through by calculations based on forecast and the sales department. The end result was the table shown below, with the most accurate figures for demand in the eyes of the Company.

Table showing the demand data for each customer in tonnes/annum

Customer	Grade	Quality	Quantity	Customer	Grade	Quality	Quantity
1	-	PR	296	44	-	ST	1,978
2	-	ST	219	45	-	PR	143
3	-	ST	471	46	-	ST	2,500
4	-	PR	365	47	-	PR	1,500
5	-	ST	139	48	-	PR	2000
6	-	ST	5,124	49	-	ST	1,200
7	-	ST	450	50	-	ST	480
8	-	ST	400	51	-	PR	5,000
9	-	PR	1,782	52	-	ST	3,500
10	-	PR	786	53	-	ST	120
11	-	ST	174	54	-	ST	1,000
12	-	ST	602	55	-	ST	311
13	-	ST	52	56	-	ST	531
14	-	ST	374	57	-	ST	11,000
15	-	ST	700	58	-	PR	572
16	-	ST	198	59	-	PR	429
17	-	ST	621	60	-	PR	374
18	-	PR	399	61	-	PR	174
19	-	ST	1,160	62	-	PR	905
20	-	ST	75	63	-	ST	100
21	-		473	64	-	SS	1,248
22	-	ST	1,250	65	-	PR	1,500
23	-	PR	195	66	-	ST	1,750
24	-	PR	319	67	-	ST	2,493
25	-	PR	90	68	-	ST	27
26	-	PR	2,000	69	-	PR	210
27	-		2,000	70	-	PR	1,445
28	-	PR	300	71	-	PR	1,800
29	-	PR	2,000	72	-	ST	125
30	-	PR	442	73	-	ST	540
31	-	ST	932	74	-	ST	750
32	-	ST	1,200	75	-	PR	750
33	-	ST	44	76	-	ST	3,655
34	-	PR	384	77	-	PR	1,107
35	-	ST	122	78	-	PR	1,053
36	-	ST	150	79	-	ST	1,064
37	-	ST	124	80	-	ST	403
38	-	PR	1,655	81	-	ST	6,981
39	-	ST	114	82	-	ST	5,561
40	-	PR	186	83	-	ST	6,770
41	-	ST	349	84	-	PR	8,997
42	-	PR	200	85	-	ST	1,989
43	-	ST	141	86	-	ST	1,679

Appendix 8

Trunking and Tanker costs in €/tonne, for the first 50 customers for the Base Case, the Optimum scenario and three different feasible scenarios as explained in figure 3.1

Customer	Factory to FS Optimum	Factory to FS Base Case	Factory to FS Scenario (a)	Factory to FS Scenario (b)	Factory to FS Scenario (c)	Tanker Cost Optimum	Tanker Cost Base Case	Tanker Cost Scenario (a)	Tanker Cost Scenario (b)	Tanker Cost Scenario (c)
	Euros Per tonne									
1	50.00	53.33	53.33	53.33	53.33	12.81	12.81	12.81	12.81	12.81
2	71.02	70.40	70.40	70.40	70.40	12.81	12.81	12.81	12.81	12.81
3	71.02	70.40	70.40	70.40	70.40	12.81	12.81	12.81	12.81	12.81
4	50.00	53.33	53.33	53.33	53.33	11.74	17.52	17.52	17.52	17.52
5	50.00	53.33	53.33	53.33	53.33	11.74	12.81	12.81	12.81	12.81
6	26.04	32.50	32.50	32.50	32.50	9.26	21.59	21.59	21.59	21.59
7	87.48	70.40	70.40	70.40	70.40	15.56	38.67	38.67	38.67	38.67
8	31.25	32.50	29.17	29.17	29.17	12.81	28.11	12.81	12.81	12.81
9	47.92	53.33	52.08	52.08	52.08	12.81	28.11	12.81	12.81	12.81
10	47.92	53.33	52.08	52.08	52.08	12.81	28.11	12.81	12.81	12.81
11	52.92	75.00	60.42	60.42	60.42	12.81	40.15	12.81	12.81	12.81
12	70.81	70.40	70.81	70.81	70.81	12.81	40.15	12.81	12.81	12.81
13	87.48	70.40	70.40	70.81	70.81	21.48	28.74	28.74	28.74	28.74
14	87.48	70.40	70.40	70.81	70.81	21.48	28.74	28.74	28.74	28.74
15	70.81	53.33	68.75	68.75	68.75	41.85	74.07	41.85	41.85	41.85
16	87.48	70.40	70.40	70.81	70.81	12.81	39.93	21.59	21.59	21.59
17	67.50	53.33	68.75	68.75	68.75	12.81	39.93	21.59	21.59	21.59
18	87.48	70.40	90.60	90.60	90.60	12.59	44.96	9.26	3.70	3.70
19	67.50	53.33	68.75	68.75	68.75	12.59	44.96	9.26	3.70	3.70
20	67.50	53.33	68.75	68.75	68.75	12.59	43.59	12.81	12.81	12.81
21	85.19	70.40	85.19	85.19	85.19	15.56	41.85	15.56	15.56	15.56
22	72.50	53.33	72.50	72.50	72.50	15.56	41.85	15.56	15.56	15.56
23	108.33	75.00	108.33	108.33	108.33	11.11	46.15	11.74	11.74	11.74
24	72.50	70.38	72.50	72.50	72.50	14.44	41.85	14.44	14.44	14.44
25	62.90	77.06	62.90	62.90	62.90	16.67	38.26	16.67	16.67	16.67
26	24.31	24.31	24.31	24.31	24.31	16.67	38.26	16.67	16.67	16.67
27	24.31	24.31	24.31	24.31	24.31	16.67	38.26	16.67	16.67	16.67
28	24.31	24.31	24.31	24.31	24.31	37.04	31.59	25.19	25.19	25.19
29	52.08	57.08	54.17	54.17	54.17	16.67	38.26	16.67	16.67	16.67
30	22.29	0.00	0.00	0.00	0.00	16.67	24.89	24.89	24.89	24.89
31	22.29	0.00	0.00	0.00	0.00	16.67	38.26	38.26	38.26	38.26
32	52.08	57.08	52.08	52.08	52.08	16.67	41.15	16.67	16.67	16.67
33	43.33	0.00	43.33	43.33	43.33	37.04	90.37	48.15	48.15	48.15
34	47.50	70.38	43.33	43.33	43.33	16.67	35.41	24.07	24.07	24.07
35	22.29	0.00	0.00	0.00	0.00	16.67	31.59	31.59	31.59	31.59
36	65.60	77.06	62.90	62.90	62.90	16.67	36.37	38.26	38.26	38.26
37	22.29	0.00	0.00	0.00	0.00	16.67	40.19	40.19	40.19	40.19
38	0.00	0.00	0.00	0.00	0.00	14.37	36.37	36.37	36.37	36.37
39	85.40	77.06	62.90	62.90	62.90	11.11	36.37	36.37	36.37	36.37
40	0.00	0.00	0.00	0.00	0.00	14.37	27.74	27.74	27.74	27.74
41	0.00	0.00	0.00	0.00	0.00	14.37	22.00	22.00	22.00	22.00
42	0.00	0.00	0.00	0.00	0.00	36.37	16.26	16.26	16.26	16.26
43	0.00	0.00	0.00	0.00	0.00	36.37	14.37	14.37	14.37	14.37
44	34.15	29.98	29.98	34.13	25.40	16.74	21.93	21.93	16.74	47.41
45	56.46	56.46	56.46	56.46	56.46	11.70	16.74	16.74	11.70	44.37
46	34.15	29.98	29.98	34.13	25.40	13.96	27.41	27.41	13.96	47.41
47	20.83	20.00	20.00	20.83	0.00	34.26	34.26	34.26	34.26	50.96
48	34.15	29.98	29.98	34.13	25.40	34.26	34.26	34.26	34.26	50.96
49	20.83	20.00	20.00	20.83	0.00	27.41	27.41	27.41	27.41	50.96
50	20.83	20.00	20.00	20.83	0.00	11.70	18.93	18.93	11.70	44.37

Appendix 9

Examples of the Centre of Gravity analysis conducted in order to find the optimum locations for the filling stations. In this appendix the Italian and Spanish clusters are present.

In order to understand more clearly the model itself and the outputs of the model, the elements of the model shown in this appendix will be explained and a worked through example of the analysis completed for one cluster is going to be presented.

As it was explained in chapter 2, every customer's location in each cluster was determined by a Cartesian coordinate system. As such their location in terms of x and y direction was known. Their demand was also given as shown in appendix 7c. This data were the inputs of the model, as shown in the table: x, y and w respectively for every customer in every cluster. Input (w) is the customer weight derived by the demand of each customer. The customer weight along with x and y were used in equations 2.3, 2.6,7 (sections 2.3.1 and 2.3.2 in the text) to derive the Optimum point within the Cartesian coordinate system of each cluster (X,Y) for a depot was derived as well as the distances between the customers and the optimum point (X,Y). In this appendix all of the above data that are shown are for the Italian and Spanish clusters.

Inputs and Outputs of the analysis conducted for the Spanish and Italian Clusters

North Italy Cluster (Milano)

				x	y	w
X:	2.5475	Customer	1	1.9	9.6	0.44
Y:	4.0871	Customer	2	2.1	5.1	12
		Customer	3	2.1	0.7	4.42
d1	5.5508	Customer	4	2.8	4.1	20
d2	1.1073	Customer	5	2.8	4.1	9.32
d3	3.4165	Customer	6	2.8	4.1	0.9
d4	0.2529					
d5	0.2529					
d6	0.2529					

South Italy Cluster

				x	y	w
X:	9.9740	Customer	1	1	9.75	6
Y:	4.1053	Customer	2	2	10.2	2
		Customer	3	2	7.75	3
d1	10.2569	Customer	4	2	8.3	2.2
d2	10.0061	Customer	5	1	5.3	2.5
d3	8.8676	Customer	6	17	0.65	20
d4	9.1341					
d5	8.9144					
d6	7.4285					

North east Italy Cluster

				x	y	w
X:	3.0099	Customer	1	2.2	2.1	3.84
Y:	2.2415	Customer	2	2.8	1.7	1.22
		Customer	3	3.65	2.5	1.5
d1	0.8221	Customer	4	4.95	2.9	1.24
d2	0.5808					
d3	0.6903					
d4	2.0488					

Barcelona

				x	y	w
X:	2.1927	Customer	1	1	4.05	4
Y:	3.8452	Customer	2	2	3.25	17.8
		Customer	3	2	4.5	0.78
d1	1.4479	Customer	4	3	5.05	7.7
d2	0.9737					
d3	0.6089					
d4	1.1102					

North Spain - Bilbao

				x	y	w
X:	7.4105	Customer	1	1.4	4.7	2.96
Y:	1.5988	Customer	2	1.7	4.35	2.19
		Customer	3	1.9	3.9	4.71
d1	1.3009	Customer	4	4.5	3.95	3.65
d2	0.8873	Customer	5	4.3	2.45	1.39
d3	0.6739	Customer	6	8.8	0.9	51.24
d4	1.9574					
d5	2.3982					
d6	7.0180					

South East Spain

				x	y	w
X:	6.6942	Customer	1	3	12.1	3.74
Y:	3.8457	Customer	2	1	11.2	0.52
		Customer	3	6	6.35	1.98
d1	7.9758	Customer	4	6	6	6.21
d2	7.2049	Customer	5	11	6.1	0.75
d3	4.2121	Customer	6	10	0	15
d4	3.6449	Customer	7	1	0.7	4.5
d5	9.0298					
d6	8.3249					
d7	3.7449					

For the purposes of this example the North – East Italian cluster is going to be used. After the cluster was determined a Cartesian coordinate system was inserted in order to find the relative distances of the customers and thus to enable the author to use the model to determine the optimum location for the filling station. The map below illustrates the NE Italian cluster. It is noted that the Cartesian coordinate system has been inserted and the relative positions of the customers have thus been found by measuring the coordinates of the points that represent the customers in this cluster.

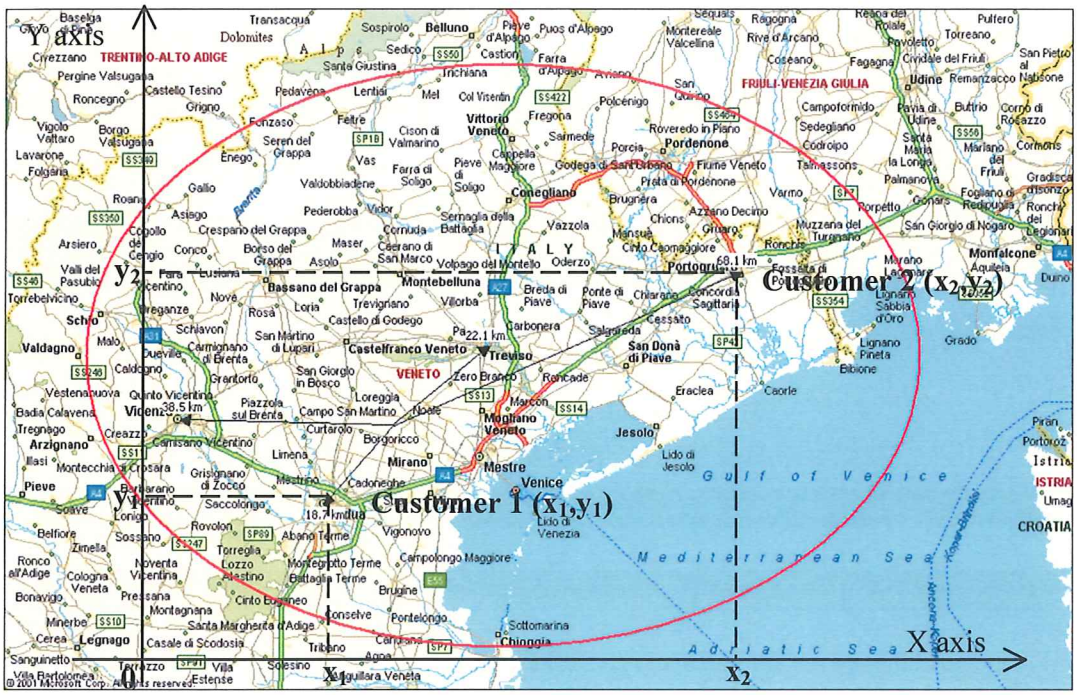


Figure illustrating the use of the Cartesian coordinate system to determine the relative positions of the customers to the optimum point (Centre of Gravity)

At this point it must be noted that the scale of the maps that each cluster is presented is irrelevant to the result of the model. That is because each cluster is treated as a separate Cartesian coordinate system and as such the positions of the customers and their relative distances are confined in their respective cluster – coordinate system.

In the above figure for reasons of simplicity, the positions of only two customers have been graphically shown; Customer 1 with coordinates (x_1, y_1) and Customer 2 with coordinates (x_2, y_2). With the figures given for the demand of each customer the customer weight was determined. The customer weight was simply the customer demand (pigment

in tonnes) divided by 100 in order to avoid complex calculations with the resulting figures.

With this data gathered, the Centre of Gravity of each cluster was determined by inserting the figures for each input the equations presented in Chapter 2. More specifically this data was inserted into equations 2.6 and 2.7. These equations yielded the coordinates (X,Y) of the Centre of Gravity of the system. By using equation 2.3 in Chapter 2 the distance between each Customer and the Centre of Gravity was determined.

North east Italy Cluster							
					x	y	w
X:	3.0099		Customer	1	2.2	2.1	3.84
Y:	2.2415		Customer	2	2.8	1.7	1.22
			Customer	3	3.65	2.5	1.5
d1	0.8221		Customer	4	4.95	2.9	1.24
d2	0.5808						
d3	0.6903						
d4	2.0488						

Table showing the data of the model for the NE Italy cluster

In the above table the relative distances between the customers and the centre of gravity are denoted d1, d2, etc., the customer weight is denoted by w, the coordinates of the customers are denoted by (x_1, y_1), (x_2, y_2), etc., and the coordinates of the Centre of Gravity is denoted by (X, Y).

As the Centre of Gravity is found, the position ('XY' coordinates) of the point is marked on the map. By using the Microsoft AutoRoute Express 2003® software the pragmatic distances of the customers, manufacturing plants etc. to the optimum point were determined.

Having calculated the locations of the filling stations on the map, and the distances between each point of interest, a table showing all of the pragmatic distances was constructed – appendix 7a. The cost of each scenario was then calculated by using the figures of cost (€/Km) for costs associated with Kilometric distances like tanker or trunking travel and (€/tonne) for costs associated with the handling of the material at the filling stations.

Appendix 10
The German Road Tax analysis

The following table illustrates the data for the German road tax analysis. For each scenario there are the road tax affecting the primary transport (trunking) and the road tax affecting the secondary transport (tankers) for each customer served by the German cluster. In the feasible scenario the German road tax affects only the secondary transport since the filling station is situated in Belgium.

Some customers within the German cluster receive more than one grade of pigment, and as such in this context one customer is treated as two different customers. This is done because different grades of pigment cannot be mixed together and transported by the same vehicle. This is illustrated in the table by two customers having the same identifying number.

In order for the table to be more clearly understood, the appearing figures will be briefly explained. Consider the movement of pigment as described in figure 1.1. The **Trunking Road Tax** is the cost associated with the Km travelled by primary transport within German soil. The **Tanker Road Tax** is the cost associated with the Km travelled by secondary transport from the Filling station to the customer and back.

Customer	Proposed		Base Case		Feasible scenario
	Trunking Road Tax	Tanker Road Tax	Trunking Road Tax	Tanker Road Tax	Tanker Road Tax
1	576.35	2,294.00	627.81	1,446.14	3,059.28
2	41.66	72.17	45.38	42.41	136.45
3	138.88	216.50	151.28	127.22	409.35
3	1,451.30	1,752.86	1,580.88	1,623.71	3,307.38
4	1,013.82	1,225.12	1,104.34	1,134.85	2,311.61
5	291.65	405.23	317.69	801.04	553.19
6	3,187.30	7,689.98	3,471.88	28,635.07	0.00
7	90.27	372.00	98.33	482.11	335.40
8	159.71	1,155.68	173.97	1,368.96	965.71
9	34.72	450.12	37.82	381.92	508.03
Total	**6,985.66**		**7,609.38**		**11,586.39**