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LLENROC PLASTICS EUROPE[1]

by

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ABSTRACT

The Llenroc Plastics corporation is a major manufacturer of high pressure decorative laminates with customers spread over a large geographical area. This work focuses on the distribution system of the company.

The study is composed of three main cases. The first case deals with the transportation system of a regional warehouse. The second case focuses on inventory control policies. Finally, a complete redesign of the warehousing system is considered in the last case.

This study forms the basis of a series of lectures in production and operations management. This analysis is supported by several software tools which aim at reducing the computational burden associated with the analysis of a real case while preserving the experimenting freedom which is necessary for educational purpose.

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Introduction

The Product

The Llenroc Plastics corporation is a major manufacturer of high pressure decorative laminates (HPDL). These laminates are found in counter tops in kitchens and bathrooms, are used as wall surfaces in homes, mobile homes, and offices, and are used by furniture manufacturers to fabricate tables, desks, and cabinets for both home and office use. They are very popular due to their low price, high durability and wide variety of colors and patterns.

Each piece of HPDL consists of several layers of different types of papers which are each impregnated with resins and pressed together at high temperatures. The top layer, which is used for protection, is colorless and transparent. The second layer is a single sheet of decorative paper which provides the color and the pattern to the surface. The next layers are made of Kraft paper sheets. The number of Kraft sheets determines the strength of the final product. Currently, there are 180 different colors and patterns and 9 standard sizes.

All the products Llenroc manufactures and distributes are laminates. The production plant is unique. After manufacturing, the laminates are stored in the central warehouse which is located with the production plant. The laminates flow then from the central warehouse to regional warehouses and finally, from the regional warehouses to the customers (OEMs or distributors). All these shipments are performed by trucking fleets directly operated by Llenroc Plastics.

The Market

The HPDL market is not large. It is expected to be approximately 480 million ECU's in the current year. This market is divided into three segments: direct sales (22%), residential (35%), and commercial specifications (43%). Llenroc Plastics has historically concentrated on direct and residential sales with only 8% of its business in the commercial specifications segment. Overall, Llenroc's projected current year sales are $81.6 million ECU's. Future market growth in real terms is expected to be about 4% per year, with most of it coming in the specification segment.

The major competitors in this market are Wilson and Formica. As shown in the table below, these companies dominate the industry in terms of market share, per unit production and distribution costs, and production capacity. Furthermore, they presently dictate the industry standards for product variety, quality, and customer service. Consequently, all financial and operational decisions must consider the impact they will have on the company's relative competitiveness.

Comparative Market Share and Cost Analysis

Company	Market Share	Raw Material	Factory cost	Freight
	(%)	ECU/sqm	ECU/sqm	ECU/sqm
Wilson	39	1,80	1,07	0,16
Formica	26	1,82	1,32	0,17
Llenroc	17	1,83	1,30	0,22
Nevamar	10	1,89	1,48	0,20
Micarta	4	1,92	1,46	0,23

An Overview of the Project

The complete project aims at a redesign of the distribution systems of Llenroc Plastics. The study is split into three main cases.

The first case deals with customer service and transportation issues associated with the operations of one of the regional warehouses. Here we examine the current operational policies, analyze customer demand, evaluate alternative trucking routes and schedules, and finally determine whether or not it is cost effective and beneficial from a service viewpoint to replace a truck fleet by a contract fleet.

In the second case, we focus on inventory aspects. Here samples of demand data are studied and inventory policies for single- and multi-echelon systems are reviewed. Both the customer service and the cost effectiveness are considered.

In the light of the results for the first two cases, the complete warehousing system is redesigned in the third case. The number of warehouses, their location and the assignment of sales regions to warehouses are reconsidered. The transportation routes, their frequency and the inventory policies are established. A trade-off between cost, flexibility and customer service is aimed at here.

1. REGIONAL TRANSPORT SYSTEM

The general question which is tackled in this case is how to organize the deliveries from a regional warehouse to its customers in order to provide the best service at the lowest cost. Should we subcontract the deliveries or use our own fleet and if we use our own fleet, how often should we send trucks to our customers? These are the two crucial questions which must be eventually answered in this case.

In order to have a clear picture we will examine the actual transportation system in the Benelux region[2]. This region is supported by the Brussels warehouse and transportation center. The policy in operation here is standard for all Llenroc warehouses. The orders are received in the morning, picked during the day, loaded onto trucks in the evening and shipped to customers the following morning. The trucking fleet is under the control of a dispatcher who selects on this daily basis the route that each truck will follow. The orders are then loaded onto the truck in the reverse sequence of destinations specified in the route in order to facilitate the unloading.

In order to evaluate the present situation, an economic model of transportation cost is first needed (Assignment 1.1). With this model, we can determine the most economical truck routing under this policy of daily shipments (Assignment 1.2). We then reconsider the frequency of the shipments. By consolidating the shipments, better truck utilizations can be achieved (Assignments 1.3). Finally, the subcontracting of the distribution is considered in Assignment 1.4 and final recommendations for the distribution system of a regional warehouse are proposed.

Assignment 1.1 Economic model of transportation cost.

By analyzing the capital and operating costs of a trucking fleet, the following cost parameters can be determined: the weekly cost T of owning a truck, the cost K per kilometer driven and the cost H per driver hour. For example, using the data given in Table 1.1 and a weekly interest rate of 12%/52, the equivalent weekly rental cost T of a truck was found to be 324 ECU's. The knowledge of these parameters allow different truck routes and schedules to be evaluated and compared. A solution with t trucks which all together cover k kilometers per week in h driving hours would cost:

$$\text{Weekly transportation cost} = t*T + k*K + h*H \text{ ECU's}$$

Assignment 1.2 Daily shipment policy.

Here we evaluate the daily shipment policy in the Brussels transport center. This center serves the customers in the Benelux and in the north of France (see Figure 1.1). Table 1.2 shows a simplified but representative order file for a week. The dispatcher sees these orders one day at a time and selects the routes the trucks will follow to deliver these orders. His objective is to minimize the transportation costs, that is, the number of trucks and the length of the routes. The task is thus a mixture of scheduling (for reusing the trucks as much as possible) and of routing (for minimizing the distances driven). The optimization is constrained by the following:

- every order must be processed immediately (shipped on the following day);
- the truck capacity cannot be exceeded;
- a truck can only be reused the day after it comes back.

Each solution can be evaluated by means of the economic model developed in Assignment 1. To ease the computational burden of this assignment, the spreadsheet TRUCKS.XLS has been developed. This spreadsheet automatically computes the length and duration of any route and checks the truck

[2] All the real data on which this case is based were modifed for obvious reasons.

capacity. The spreadsheet also checks to see that each order for the day is assigned to a route. With the spreadsheet, different routing alternatives can be quickly tested. Figures 1.2 and 1.3 show a typical working screen and a daily cost report of this spreadsheet.

By trial and error the most economical solution can be determined. The table below summarizes the performances of a good solution for daily shipment policy. For each day of the week, this table gives the number of trucks used to deliver the daily orders, the distance these trucks will cover during their trip and the total number of hours they need. The delivery time for a customer is defined as the time between the moment the truck leaves the warehouse and the moment it arrives at this customer.

Daily Shipment	Mon	Tue	Wed	Thu	Fri	weekly total	cost / unit (ECU's)	total cost (ECU's)
# truck used	2	3	2	3	2	6	324.00	1944
# km driven	2065	2276	2034	2201	1955	10531	0.25	2633
# driving hours	48	52	48	51	47	246	15.00	3683
worst delivery time	2.20	2.16	2.36	1.56	2.26			**8260**
avg. delivery time	1.30							

Assignment 1.3 Consolidated shipment policy.

Here the daily shipment constraint is relaxed and the cost benefits which could be achieved through consolidating shipments are estimated. The last column of Table 1.2 shows the total shipments to each location for the week. Assuming that these shipments can be made any time during the week, a new routing and scheduling of the trucks can be determined.

To ease the computational burden of this assignment, the spreadsheet MGMT.XLS has been developed. This spreadsheet is like the spreadsheet TRUCKS.XLS used in Assignment 1.2 but it allows the total weekly demand to be assigned to different days of the week. That is, the daily order file is freely created on the basis of the total weekly demand. Again, by trial and error, a good solution can be determined. For this example, we selected the daily order file depicted in Figure 1.4 and the truck schedule shown in Figure 1.5. Here are the performances of this solution. Note that compared to the daily shipment policy, the costs have been reduced by a factor 2.5.

Consolid. Ship.	Mon	Tue	Wed	Thu	Fri	weekly total	cost / unit (ECU's)	total cost (ECU's)
# truck used	3	2	1	3	1	3	324.00	972
# km driven	1282	1214	174	1645	0	4315	0.25	1079
# driving hours	27	24	4	33	1	90	15.00	1349
worst delivery time	0.71	0.66	0.15	1.12	0.00			**3400**
avg. delivery time	0.40							

The problem of assigning fractions of total demand at a location to different routes to minimize transportation cost subject to the truck capacity constraint can be formulated and solved as a mathematical program. The combinatorial aspect of the problem can be simplified by selecting a set of possible routes a priori. For each route, the fraction of each node demand which is delivered along that route and the frequency of use of that route can be selected as decision variables. Both the costs and the constraints (truck capacity and node demand) can then be expressed as linear functions of these variables. The problem is of a mixed-integer nature since an integer number only of trucks can be used. This formulation specifies along which routes each node demand is best satisfied. It does not tell when these routes should be used. A schedule of the routes must be determined a posteriori.

Assignment 1.4 Common Carrier

An alternative to using Llenroc Plastics' trucks to deliver product would be to ship the product to customers using common carrier trucks. The cost advantage that the common carrier has over Llenroc Plastics is that it can achieve much higher utilization of its trucks. Even if Llenroc sent full trucks only, they would travel back empty and often over considerable distances.

The disadvantage of using common carrier is the delay involved. The transportation time is comparable to Llenroc's performance, but the order pick-up and shipment consolidation time can add 3-5 days to delivery time. This would be unacceptable for emergency orders. Note, however, that even using company trucks, if the demand consolidation ideas of Assignment 3 are implemented, Llenroc will impose a similar shipment consolidation delay. The common carrier charges to Llenroc is based on the number of square meter-kilometers shipped. A typical common carrier quotes 0.00008 ECU's / (sqm * km). Based on the weekly data, the common carrier costs amount to 2631 ECU's per week.

Assignment 1.5 Recommendations

The different assignments of this case mainly focused on the economic aspects of the three alternatives and clearly indicate that the daily policy which is currently in use should be abandoned. The choice between using common carriers or an own fleet with consolidated shipments is not so obvious. The common carriers offer a small financial advantage. However, other major criteria speak in favour of keeping its own fleet. These are the quality of service in terms of delivery times, the predictability of the truck departure and arrival times and the flexibility of the system with respect to changes of volumes and/or place.

A possible solution would consist in mixing both approaches by differentiating the customers. The large customers (OEM mainly) who order in full truckloads could be directly served by a truking fleet operated by Llenroc. This maintains a high quality of service while keeping the costs low. This trucking fleet could also be replaced by a contract carrier who provides the same guarantees in terms of service. The contractual price coud be lower than that of operating its own fleet if the contract carrier has good backhaul opportunities. Small customers, on the other hand, can only be served by common carrier.

Table 1.1 Truck capital and operating costs.

Acquisition Cost	60,000	ECU's
Wholesale value after 5 years	12,000	ECU's
Fuel Cost	0.2	ECU's per km
Maintenance and Tire Costs	0.1	ECU's per km
Annual registration	500	ECU's
Insurance	2000	ECU's
Driver cost	15	ECU's per hour

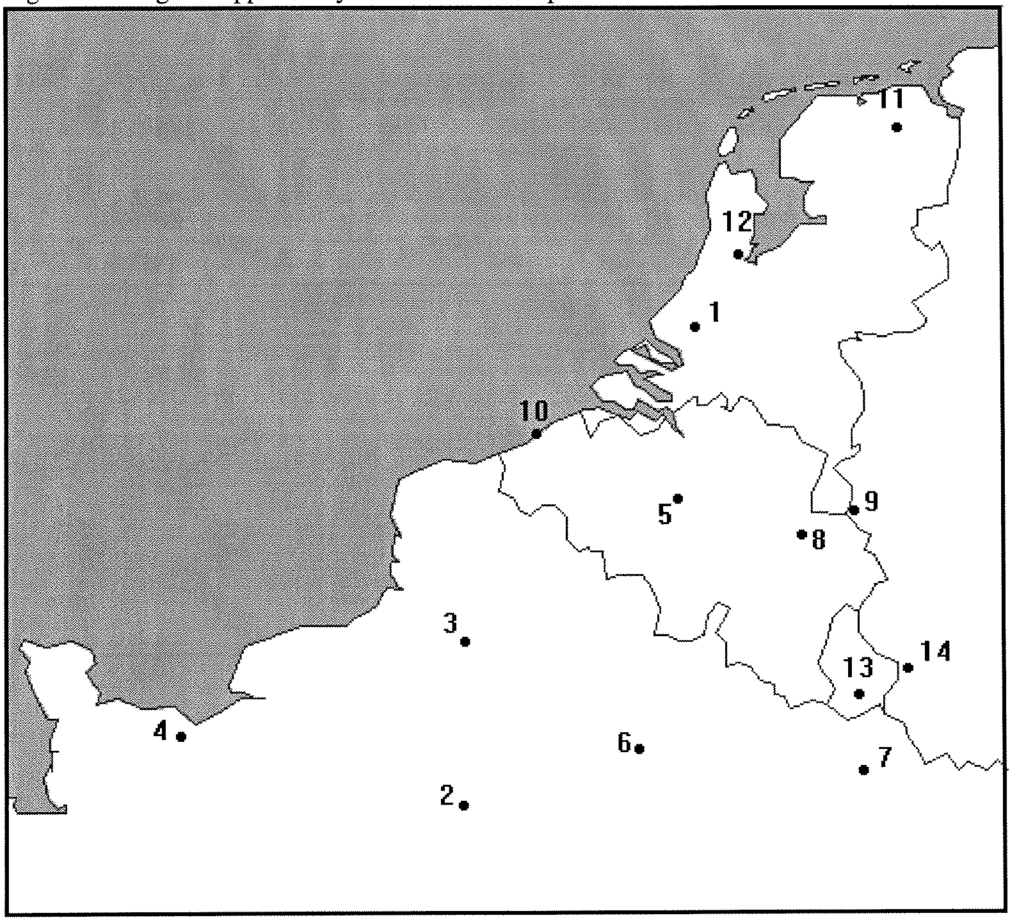
Table 1.2. Daily order file for the Brussels transport center.

	Mon.	Tue.	Wed.	Thr.	Fri.	Total
1 Rotterdam, NL	1837	2690	1369	1760	1124	8780
2 Paris, F	821	646	1064	1329	152	4012
3 Amiens, F	1234	701	1753	1775	1627	7090
4 Caen, F	4118	7865	10722	8787	9619	41112
5 Brussels, B	3181	11311	10463	8549	9001	42503
6 Reims, F	287	222	754	1114	1723	4100
7 Metz, F	240	469	620	549	489	2366
8 Liège, B	356	4643	2362	4550	1441	13352
9 Aachen, D	14923	14945	1313	12060	2002	45244
10 Oostende, B	502	2053	2351	40	608	5554
11 Groningen, L	82	2357	806	1387	642	5274
12 Amsterdam, NL	934	1061	455	129	1469	4048
13 Luxembourg, L	1157	1402	204	2941	3004	8707
14 Trier, D	884	769	1060	3239	5628	11581

Table 1.3 Distances between cities served by the Brussels transport center

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Rot	Par	Ami	Cae	Bru	Rei	Met	Lie	Aac	Oos	Gro	Ams	Lux	Tri
1 Rotterdam	0	362	263	444	116	289	322	159	164	126	192	57	271	272
2 Paris	362	0	113	195	255	125	271	294	330	257	545	418	277	313
3 Amiens	263	113	0	202	173	138	282	239	275	149	452	319	266	296
4 Caen	444	195	202	0	372	308	460	440	476	315	634	499	456	489
5 Brussels	116	255	173	372	0	172	223	87	118	106	292	169	179	192
6 Reims	289	125	138	308	172	0	152	183	216	226	455	340	151	187
7 Metz	322	271	282	460	223	152	0	165	175	318	434	357	51	73
8 Liège	159	294	239	440	87	183	165	0	37	193	283	194	117	115
9 Aachen	164	330	275	476	118	216	175	37	0	221	261	188	124	112
10 Oostende	126	257	149	315	106	226	318	193	221	0	318	180	281	297
11 Groningen	192	545	452	634	292	455	434	283	261	318	0	135	385	368
12 Amsterdam	57	418	319	499	169	340	357	194	188	180	135	0	309	302
13 Luxembourg	271	277	266	456	179	151	51	117	124	281	385	309	0	36
14 Trier	272	313	296	489	192	187	73	115	112	297	368	302	36	0

Figure 1.1 Region supported by the Brussels transportation center.



1	Rotterdam
2	Paris
3	Amiens
4	Caen
5	Brussels
6	Reims
7	Metz
8	Liège
9	Aachen
10	Oostende
11	Groningen
12	Amsterdam
13	Luxembourg
14	Trier

Figure 1.2 Working screen for the daily shipment policy (from TRUCKS.XLS)

	A	B	C	D	E	F	G	H	I	J
1	Tuesday		Truck 3 Schedule				Number of drivers:			1
2							Truck Cap (sqm):			22500
3							Driver Day (hours):			10
4	Order	Quantity	City		Dist	Time				
5	Seq				(between cities)				TOTALS:	
6	0	0	Wh		0	0,00		Total Quantity:		22228
7	8	4643	Liege		87	1,45		Space Available:		272
8	9	14945	Aachen		37	0,62		Total Distance:		546,0
9	14	769	Trier		112	1,87		Total Time:		14,1
10	13	1402	Luxembourg		36	0,60		Total #Orders:		5
11	7	469	Metz		51	0,85		# Driver Days:		1,4
12	0	0	Wh		223	3,72		Max. days wait		0,9
13	0	0	Wh		0	0,00				
14	0	0	Wh		0	0,00				
15	0	0	Wh		0	0,00				
16	0	0	Wh		0	0,00			CHECK	
17	0	0	Wh		0	0,00		Truck Capacity fine		
18								All orders routed		

Figure 1.3 Cost summary for the daily shipment policy (from TRUCKS.XLS)

	A	B	C	D	E	F	G	H	I
1	Tuesday			BestSolution Summary Statistics					
2									
3		Routes							
4	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5		Error Messages for		Truck:
5	5	10	8	0	0		Truck Capacity fine		1
6	3	1	9	0	0		All orders routed		
7	4	12	14	0	0		Truck Capacity fine		2
8	2	11	13	0	0		All orders routed		
9	6	0	7	0	0		Truck Capacity fine		3
10	0	0	0	0	0		All orders routed		
11	0	0	0	0	0		Truck Capacity fine		4
12	0	0	0	0	0		All orders routed		
13	0	0	0	0	0		Truck Capacity fine		5
14	0	0	0	0	0		All orders routed		
15	1	1	1	1	1	drivers			
16	1,95	1,59	1,41	0	0	driving days			
17	# Orders shipped:			14			Total distance:		2129,00
18	#Orders placed:			14			Total hours:		49,48
19	Total quantity shipped:			51134			Total driving days:		4,95
20	Total quantity ordered:			51134			Worst delivery time:		1,56

Figure 1.4 Selected daily order file for the consolidated shipment policy (from MGMT.XLS)

	A	B	C	D	E	F	G	H
1	City#	City	Mon	Tues	Wed	Thurs	Fri	Total
2	1	Rotterdam	8780					8780
3	2	Paris				4012		4012
4	3	Amiens				7090		7090
5	4	Caen		20555		20556		41111
6	5	Brussels	20005				22500	42505
7	6	Reims				4100		4100
8	7	Metz	2367					2367
9	8	Liege			13352			13352
10	9	Aachen	22500	243		22500		45243
11	10	Oostende				5554		5554
12	11	Groningen	5274					5274
13	12	Amsterdam	4048					4048
14	13	Luxembourg		8708				8708
15	14	Trier		11580				11580
16		sum	62974	41086	13352	63812	22500	OK

Table 1.5 Truck schedule for the daily order file of Figure 1.4

	Monday	Tuesday	Wednesday	Thursday	Friday
Truck 1	Rotterd. / Amsterd. / Groning.		Brussels	Aachen	Liège
Truck 2	Bruss. / Metz	Luxemb. / Trier / Aachen		Oost. / Amiens / Paris / Reims	
Truck 3	Aachen	Caen		Caen	

2. The Inventory Policy

Llenroc Plastics' customer service is affected by several factors: transportation time from the regional warehouse to the customer, frequency of shipments to the customers, the information system used to process orders, and the inventory policies and procedures. This case addresses issues relating to the inventory system's operation and its effect on cost and service.

Let's review some facts concerning how the supply system for finished goods operates. There are four levels, called echelons, of inventory of finished goods in this supply chain: (1) the central warehouse, (2) the regional warehouses, (3) the distributors and OEMs, and (4) the customers. There is inventory of laminates in each echelon. Unfortunately, in the present situation, each echelon operates independently of the others. That is, ordering decisions made at one echelon do not take into account the inventory status at other locations. This lack of co-operation results in inefficient shipment decisions and in system instabilities. These consequences are studied in great details in Assignment 2.1 where a single product multi-echelon system is considered. The study clearly indicates which information is required at which echelon for an inventory control policy to perform well.

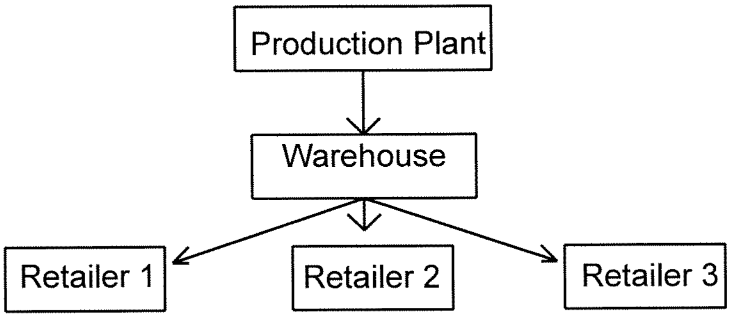
Assignment 2.2 aims at applying the inventory policy suggested by assignment 2.1 to the complete Llenroc Plastics' product palette. The stress is put on the importance of the coefficient of variation of the demand and on notions of risk pooling. These aspects are crucial for the next case where the number and the location of the regional warehouses will be reconsidered.

Assignment 2.1. The distribution games

When ordering decisions made at one echelon do not take into account the inventory status at other locations, instabilities can be created. For example, a regional warehouse places orders with the central warehouse based on its inventory position without regard for the inventory situation at the central warehouse, any other regional warehouses, or the OEMs and distributors that it supplies. As a consequence, there may be a perceived shortage of inventory for one item at the central warehouse (a regional warehouse has placed an order for the item on the central warehouse that can not be completely satisfied immediately) while there is a considerable amount of stock at all the lower echelon locations for this item. In response to the perceived shortage, the manufacturing plant may then rush the order through the production cycle. Because production of other items is sometimes delayed, the actual lead times can differ substantially from planned lead times. As a result, regional warehouses can run out of stock.

Inadequate shipment decisions can also result from this lack of information. Assume for example that several regional warehouses place over a short period inventory replenishment orders which together exceed the available stock at the central warehouse. Because the central warehouse proceeds in FIFO order, some regional warehouse will get their complete order while other won't get anything. This could result in lost sales.

In order to illustrate these drawbacks, two simulation games have been developed. They both consider the single product multi-echelon inventory system depicted below.



In this system, the products flow from the producer to the central warehouse and then to the retailers where they are finally sold to the customers. To compensate the lead times between the echelons, inventories exist both at the warehouse and at the retailers. The first game consists in controlling the inventories. At each level, the daily decision is: " how much to order?" An illustration of the game screen is given in Figure 2.1. Playing this game allows to identify the information which is required to perform an efficient inventory control.

The second game allows (Q,R) policies to be simulated for a given period. If orders are competing for items at the warehouse, an allocation scheme which preserves fairness between the competing retailers is used. Both games allow the system characteristics to be modified. These are the lead times between the echelons, the holding costs and the order costs, the demand distribution and the reviewing period. This allows the relative importance of the different system parameters to be estimated. An illustration of the game screen is given in Figure 2.2.

These simulations showed that a classical (Q,R) policy would work quite well for the retailers. A (Q,R) policy can also be used at the warehouse if it is implemented with sufficient care. Here is a possible implementation.

1. For the computation of the reorder point, the lead time demand should be seen as the sum of the demand at the retailers and not the sum of the retailers' demands.
2. The computation of the inventory position at the warehouse should also include the inventories at the retailers. The idea followed by these first two points is that the retailer ordering process is just an intermediate filter which does not modify the global demand process. This view is valid as long as the ordering process at the retailers does not introduce too much irregularity. The following point makes this view more robust.
3. A fair allocation strategy should be used at the warehouse when its inventory gets critically small. By checking its inventory and the inventories of the retailers, the warehouse could foresee that an order will soon be issued that could not be satisfied. By reducing the last shipments, this order could nevertheless be partially satisfied. This strategy aims at avoiding stockout at the cost of suboptimal lot size.

In addition, if the holding costs are predominant, the synchronization of the warehouse with the retailers could be beneficial.

Assignment 2.2 Demand analysis and safety stock computation

In order to apply these policies to a complete product palette, let us now consider a sample of the data for the Brussels' warehouse as shown in Table 2.1. This random sample of 70 items is taken from a population of 1,620 types of finished laminates and represents total orders by part number for a typical six month period. An A-B-C categorization of these 70 items based on surface shipped allows one typical product to be extracted for each class. These are:

Class	Product	Size	Mean weekly demand	Standard deviation	Coefficient of Variation
A	Almond D	150X360	66.2	27.81	0.4
B	Almond P	90X300	11.3	8.73	0.8
C	Pigeon Blue PF	120X240	1.0	3.14	3.0

For each of these products, the safety stock as a function of the desired fill rate can be numerically computed. We therefore assume constant lead times of 2 weeks and lead time demand to be normally distributed for the first item and Laplace-distributed for the second and third items. The required safety stock was expressed as a percentage of the weekly demand for the following two practical reasons. First, it is extremely intuitive to speak of x weeks of demand as safety stock for a given product. Second, the percentage can be quite directly applied to other similar products in order to estimate the total safety stock value. To ease the computation of these plots and to be able to test the model under different assumptions, the spreadsheet SAFE3P.XLS has been developed. Figure 2.3 shows the plot for the three Llenroc reference products. This plot clearly shows that high fill rates can be obtained with a relatively low safety stock as long as the coefficient of variation of the demand remains small. Since this coefficient decreases when the demand increases, this is a big incentive for grouping the demands for a same product as much as possible.

The results show that a fill rate of 99 % can be reached with safety stocks which amount to one week for A products, to two weeks for B products and to twelve (!!!) weeks of demand for C products. These values show that good service can be provided at low cost for A and B products. For C products , on the other hand, the question of maintaining any stock in a regional warehouse should be raised.

An estimation of the safety stock value at a regional warehouse can then be obtained by applying these percentages at the whole classes . For another regional warehouse, the safety stock values could be recomputed or simply reused, depending on how much the demand pattern changes. For the central warehouse, a new computation is needed since the demand level is larger and the coefficient of variation smaller.

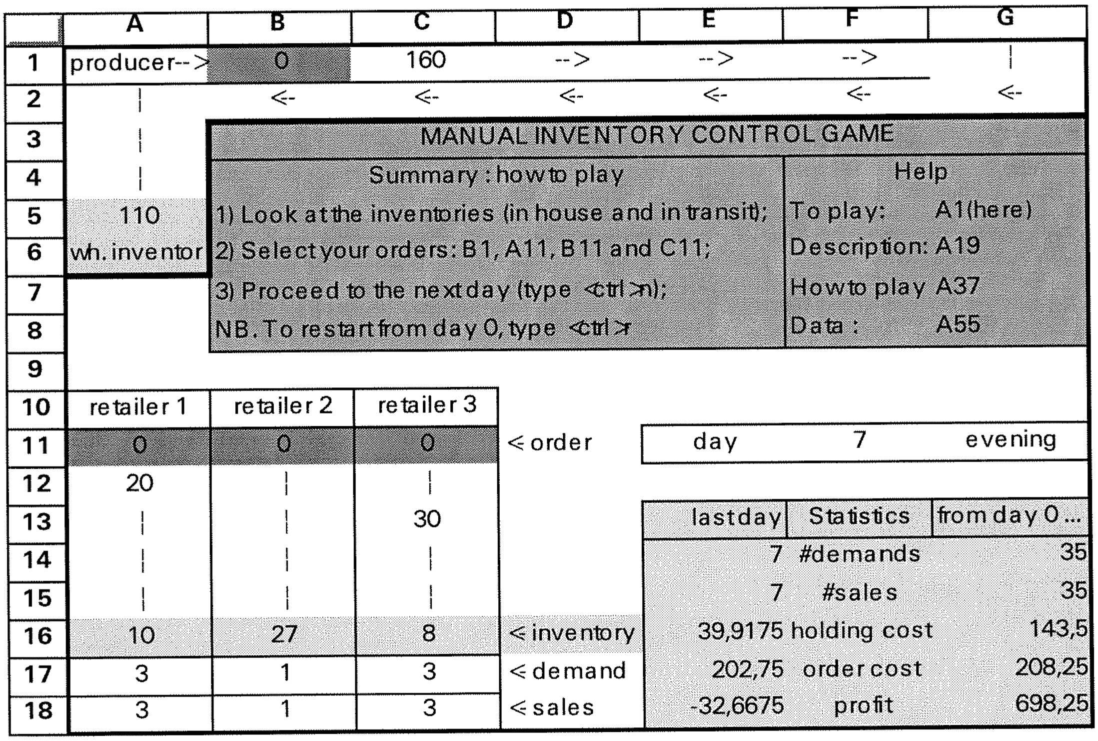
Table 2.1 Demand for a sample of products in the Brussels' region.

Description	Mean Demand	Standard Deviation	Coefficient of Variation
Almond D 60x144	66,2	27,81	0,4
Walnut V 48x96	35,6	22,42	0,6
Teak V 48x96	17,4	13,76	0,8
Almond P 36x120	11,3	8,73	0,8
Danish Walnut	9,3	8,27	0,9
Mercury 60x120	7,7	7,82	1,0
Almond Tessera 48x96	6,3	8,23	1,3
Fine Oak	5,4	6,88	1,3
Primary Red 48x120	4,6	5,50	1,2
Carnation Gloss 48x120	4,2	7,50	1,8
Almond 60x144	3,7	5,93	1,6
Fawn PB V 48x96	3,4	4,89	1,4
Almond D PF 60x120	3,1	4,72	1,5

Butcher BLock LG 36x96	2,8	5,70	2,0
Black Granite PF 60x144	2,6	5,78	2,2
Slate 48x96	2,5	4,82	2,0
Flaxseed PF 30x144	2,3	5,29	2,3
White Nugget 48x96	2,0	4,28	2,1
Royal Blue 36x96	1,9	4,98	2,6
Squash 48x96	1,8	4,53	2,5
Prima Walnut 48x96	1,7	4,63	2,7
Leather PF 60x144	1,6	3,83	2,4
Tapioca 48x144	1,5	4,41	2,9
Nubian Brown PF 48x96	1,5	4,07	2,7
Mahogany 48x96	1,4	4,55	3,2
Fudge 48x96	1,3	3,89	2,9
Lilac 48x96	1,3	3,44	2,8
Raspberry PF 30x96	1,2	4,60	3,8
Wormy Chestnut V 48x120	1,2	3,08	2,6
Cloud Marble 36x96	1,1	3,19	2,9
Pigeon Blue PF 48x96	1,0	3,14	3,0
Alabaster Glazetone PF60x144	1,0	3,40	3,4
Select Walnut 36x96	1,0	2,92	2,9
Twill V 48x96	0,9	3,34	3,6
Decora PF 48x96	0,9	3,70	4,2
Amberwood PF 48x96	0,9	3,33	3,8
Butcher Block 60x96	0,8	3,92	4,7
Caramel PF 48x96	0,8	3,11	3,9
Coral 60x144	0,8	3,21	4,3
Black Walnut 48x120	0,8	2,83	3,8
Taupe 36x96	0,7	2,85	4,0
Indigo Blue PF 48x120	0,7	2,85	4,3
Honey 60x144	0,7	2,65	4,0
Ash 60x144	0,6	2,88	4,6
Beige 60x120	0,5	2,45	4,5
Copper 48x144	0,5	2,18	4,4
Palomino Melcor 48x120	0,5	2,25	4,9
Vanilla PF 60x120	0,4	1,99	4,8
Powder Pink 36x96	0,4	1,52	4,1
Jade 60x120	0,3	1,54	4,6
Greystone 60x120	0,3	1,45	5,0
Grape 48x144	0,3	1,20	4,8
Canyon 60x96	0,2	1,10	5,3
Beige Pavia 48x120	0,2	0,86	5,1

Sparta Marble 36x144	0,1	0,66	5,3
Moonstone 36x96	0,1	0,46	5,6
Silver Plexus 48x144	0,0	0	0,0
Herringbone 48x96	0,0	0	0,0
Ginger Plume 60x144	0,0	0	0,0
Tan Plume 48x144	0,0	0	0,0
White Gold 60x144	0,0	0	0,0
Navy 48x96	0,0	0	0,0
Classic Mahogany 48x96	0,0	0	0,0
Horizon Blue 48x96	0,0	0	0,0
Parchment 60x96	0,0	0	0,0
Silver Plexux 36x144	0,0	0	0,0
Sandstone 36x96	0,0	0	0,0
Brittany 36x144	0,0	0	0,0
Ginger 60x144	0,0	0	0,0
Tweed 48x144	0,0	0	0,0

Figure 2.1 Inventory control game (from INV_CTRL.XLS)

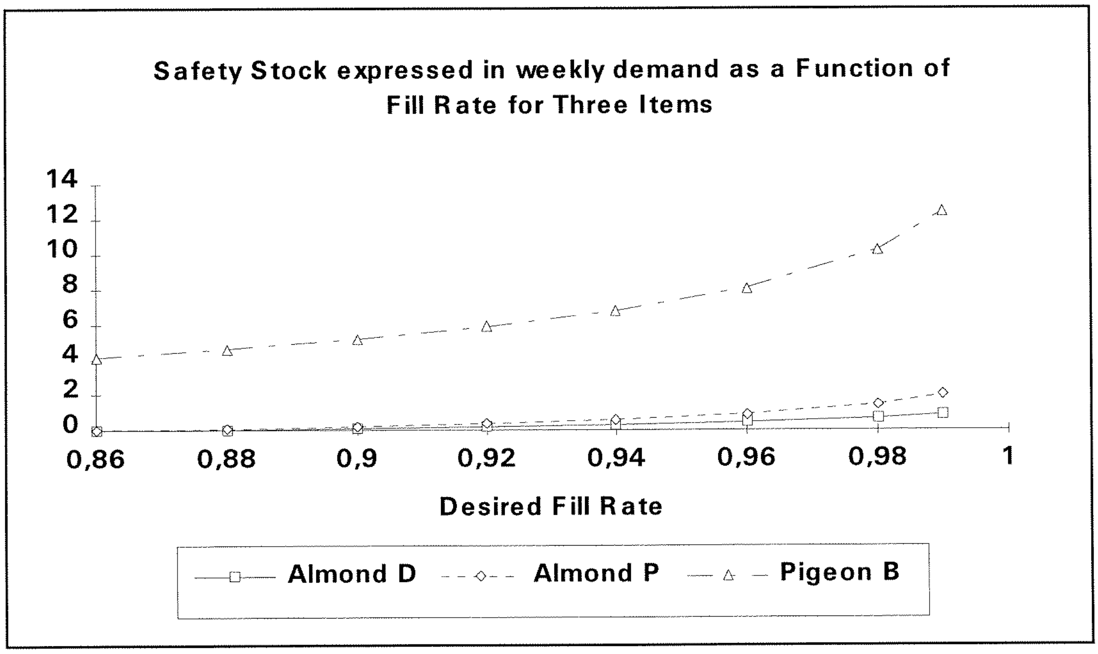


	A	B	C	D	E	F	G
1	producer-->	0	160	-->	-->	-->	|
2	|	<-	<-	<-	<-	<-	<-
3	|	MANUAL INVENTORY CONTROL GAME					
4	|	Summary : how to play				Help	
5	110	1) Look at the inventories (in house and in transit);				To play: A1(here)	
6	wh. inventor	2) Select your orders: B1, A11, B11 and C11;				Description: A19	
7		3) Proceed to the next day (type <ctrl>n);				How to play A37	
8		NB. To restart from day 0, type <ctrl>r				Data : A55	
9							
10	retailer 1	retailer 2	retailer 3				
11	0	0	0	< order	day	7	evening
12	20	|	|				
13	|	|	30		lastday	Statistics	from day 0...
14	|	|	|		7	#demands	35
15	|	|	|		7	#sales	35
16	10	27	8	< inventory	39,9175	holding cost	143,5
17	3	1	3	< demand	202,75	order cost	208,25
18	3	1	3	< sales	-32,6675	profit	698,25

Figure 2.2 Automated inventory control game (from INV_CT_A.XLS)

	A	B	C	D	E	F	G
1	AUTOMATED INVENTORY CONTROL GAME						
2	--						
3	>>> Help <<<		>>> Summary : how to play <<<			Statistics	for 1 year
4	To play:	A1(here)	1) Enter your data: C13-C18, F13-G15			#demands	1192
5	Description:	A19	2) Select your control values : F17-G18			#sales	1189
6	How to play:	A37	3) type "<ctrl>a" and wait...			holding cost	3992,09
7	Data info:	A55	4) look at the statistics			order cost	1469,50
8	Run details:	J1-R200	5) return to step 2 or to step 1			profit	30208,41
9							
10	Problem data and control values						
11	--						
12						Warehouse	Retailer
13	Year (days)		200	Lead time (days)		15	5
14	Purchase cost (/item)		70	Holding cost (/item/day)		0,0735	0,0875
15	Selling price (/item)		100	Order cost (/order)		200	2,75
16	Review period (days)		2			Warehouse	Retailer
17	New random list(True,Fal.)		TRUE	Order point		170	17
18	Ditribution (0=C,1=N, 2=U)		1	Order quantity		200	12

Figure 2.3 Safety stock computation (from SS3P.XLS)



3. The Warehouse System

Llenroc Plastics' distribution system consists of the central warehouse, located in London, and of 7 regional warehouses (Copenhagen, Hamburg, Munich, Milano, Brussels, Lyon, and Madrid). Each warehouse is responsible for a set of sales regions. There are 22 sales regions as shown on the map of Figure 3.1. The current assignment of sales regions to warehouses is given in Table 3.1. Rather than considering the detailed demand by customer, the demand by region has been aggregated in order to reduce the computational burden. This aggregated demand is also given in Table 3.1. Note that the central warehouse also plays the role of a regional warehouse.

Our task here is to redesign the complete warehousing and distribution system. We must determine the number of regional warehouses, define where they will be located and assign the sales regions to the warehouses. Our goal is to minimize all the relevant costs: warehousing, inventory, and transportation costs.

The warehouse cost depends on the volume which is processed. The curve we used in our calculation is given in Figure 3.2. This is a piecewise linear function. Its convexity is a direct consequence of the economies of scales. In our analysis, the same curve was assumed to be valid for all possible warehouse sites. Note that different considerations led to a reduction of the set of possible warehouse sites to twelve cities. These cities are marked with an asterisk in Table 3.1. As mentioned, there are existing Llenroc warehouses in eight of these cities. If we propose closing an existing warehouse, we should include the corresponding termination cost.

An approximate transportation plan is necessary for estimating the transportation cost. To simplify this evaluation, we assume that each sales region has associated with it a central break-bulk point. These break-bulk locations are indicated in Table 3.1. All shipments to that region come to the break-bulk point using long haul carrier. At the break-bulk point, the shipments to individual customers are separated and a local short haul carrier is used to move the laminates to their final customer destinations. Since these break-bulk points are predetermined, the warehouse location decision has no effect on total short haul costs. Nevertheless, these costs will be included in the total cost report. The long haul transportation from the central warehouse to the regional warehouses and from the regional warehouses to the break-bulk points can be performed by a contract fleet. The cost is estimated at 1.09 ECU per kilometer and per truck, independently of the truck load.

The inventory costs can be split into three main components : the cyclic stock, the pipeline stock and the safety stock. The cyclic stock is based on the current economic order quantities. The pipeline stock can be immediately derived from the transportation plan. The safety stock must be determined for each regional warehouse and for the central warehouse. As in the previous case, we expressed this safety stock as a percentage of the weekly demand for each product class. Note that the fill rates at a regional warehouse and at the central warehouse should be selected coherently.

The spreadsheet WCOST.WK1 has been developed to produce a rough draft of the total cost report. Based on the assignment of sales regions to warehouses, the spreadsheet will automatically calculate warehouse operating costs (see Figures 3.3 and 3.4). Based on your specification of a standard set of routes to use and your assignment of demand to these routes, the spreadsheet will automatically estimate both long haul and short haul transportation costs. Furthermore, based on your specification of average months of supply of cycle and safety stock at each location, the spreadsheet will automatically calculate the average inventory investment at each location (see Figure 3.5). All these costs are automatically included in the total cost report (see Figure 3.6). This spreadsheet allows different options to be quickly estimated.

Let us now analyze the problem and consider some possible solutions. All three cost components speak in favour of a reduction of the number of warehouses:

- The convexity of the warehouse cost curve favours large warehouse volumes.
- Because the coefficient of variation of the demand decreases when the demand increases, smaller safety stocks are needed when the demand is aggregated.
- The minimization of the transportation cost is more difficult. If several trucks of products flow every week from the central warehouse to the break-bulk point of the region, the use of a

regional warehouse can only introduce some detours. Such regions would be best served by the central warehouse directly. On the other hand, for regions with low demands, the use of a regional warehouse could allow the traffic to be aggregated over a part of the trip.

From a purely economical point of view, keeping the central warehouse only and closing all the regional warehouses is a very attractive solution. This solution could be unacceptable from the customer service point of view. For solutions with a few regional warehouses, the above mentionned rules remain valid. Warehouse volumes should be kept as high as possible and transportation detours should be avoided. Note also that the regional warehouses need not keep stock for the whole product palette. Typically, C products could be stored at the central warehouse only.

Finally, the customer service needs to be measured in the new proposed warehousing system. A curve (percentage of the demand / number of days needed to satisfy this demand) could be derived from all the variables which were defined in this case, that is, the number and location of the warehouses, the transportation plan and the inventory policies. Assumptions on the production lead time value and variability are here necessary. Three additional cases aim at improving these values. But this is another story.

4. Educational Aspects

The analysis of the Llenroc Plastics distribution system allows different logistic problems and techniques to be faced and therewith several disciplines to be reviewed.

In the first case, these are: cost modelling, cyclic scheduling, transportation problem, routing and mathematical programming. The second case reviews inventory control techniques in single and multi-echelon system and general applied probability notions. The third case requires notions of investment analysis and of customer service. It also allows social aspects to be tackled.

During the teaching of this course, a special attention is given to the quality of the team work, of the problem analysis and of the result synthesis and presentation.

[1] J. Muckstadt and P.J. Jackson, "Llenroc Plastics: a Case Study in Manufacturing and Distribution Systems Integration ", Technical Report 898, School of ORIE, Cornell University, 1990.

Table 3.1 Sales regions

	Sales Region	Break-bulk Point		Responsible Warehouse	Weekly Volume
1	Finland	Helsinki		Copenhagen	45642
2	Sweden	Stockholm		Copenhagen	155781
3	Norway	Oslo		Copenhagen	155781
4	Denmark	Copenhagen	*	Copenhagen	6435
5	North Germany	Hamburg	*	Hamburg	17216
6	East Germany	Berlin	*	Hamburg	5397
7	Central Germany	Stuttgart		Munich	72208
8	South Germany	Munich	*	Munich	18104
9	Austria	Wien	*	Munich	110128
10	Switzerland	Bern		Munich	408528
11	North Italy	Milano	*	Milano	53929
12	South Italy	Roma		Milano	46035
13	Benelux	Brussels	*	Brussels	594912
14	North France	Paris		Brussels	97624
15	SW France	Bordeaux		Lyon	144917
16	SE France	Lyon	*	Lyon	380924
17	East Spain	Barcelona	*	Madrid	31953
18	West Spain	Madrid	*	Madrid	293713
19	Portugal	Lisboa		Madrid	145765
20	Ireland	Dublin		London	76532
21	Scotland	Edinburgh	*	London	174128
22	England	London	*	London	69425

Figure 3.1 Sales regions

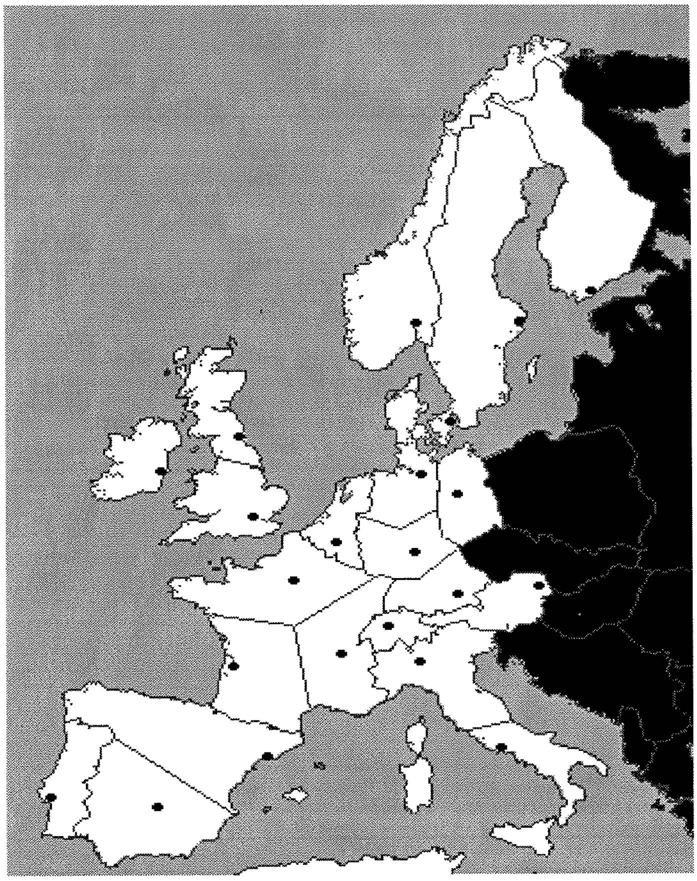


Figure 3.2 Warehouse cost model

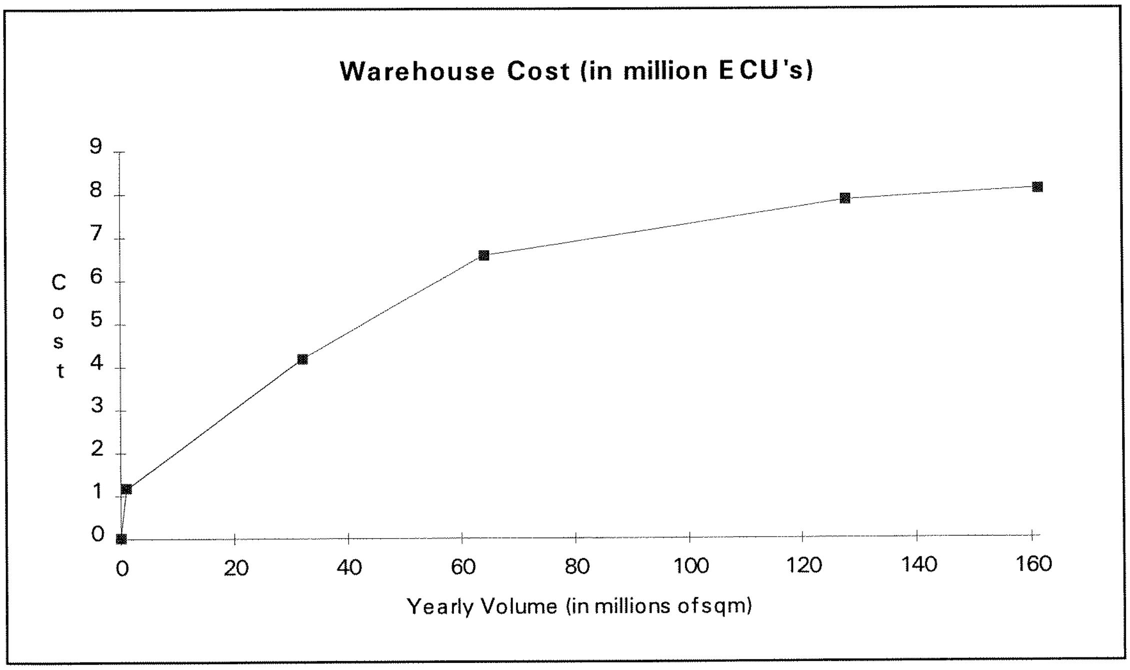


Figure 3.3. Warehouse cost summary (From WCOST.XLS)

	A	B	C	D	E	F	G
1	Result 1.1		ANNUAL WAREHOUSE COST SUMMARY (in millions)				
2							
3	Warehouse	Reg #	Volume	Cut	Base	Labor+lease	Wh. Total
4	--------------------	--------------------	--------------------	--------------------	--------------------	--------------------	--------------
5	Copenhague	4	18,91	1	1,065	1,84	2,91
6	Hamburg	5	1,18	1	1,065	0,11	1,18
7	Berlin	6	0	0	0	0	0
8	Munich	8	31,67	1	1,065	3,09	4,15
9	Wien	9	0	0	0	0	0
10	Milano	11	5,20	1	1,065	0,51	1,57
11	Brussels	13	36,01	2	1,065	3,42	4,49
12	Lyon	16	27,34	1	1,065	2,67	3,73
13	Barcelona	17	0	0	0	0	0
14	Madrid	18	24,51	1	1,065	2,39	3,46
15	Edinburgh	21	0	0	0	0	0
16	London	22	16,64	1	1,065	1,62	2,69
17							--------------
18					Grand Total:		24,17
19	Help at A21						million

Figure 3.4 Transport cost model (from WCOST.XLS)

	A	B	C	D	E	F
1	Result 1.2	WEEKLY TRANSPORTATION AND PIPELINE STOCK COSTS:				
2		LONDON TO REGIONAL WAREHOUSES				
3		Reg #	Volume/wk	Km from	Pipeline	Transportation
4				London	Stock Cost	Cost
5	Copenhague	4	363640,29	995	11235,15	3429,44
6	Hamburg	5	22613,58	710	498,55	152,18
7	Berlin	6	0	845	0	0
8	Munich	8	608967,85	640	12102,03	3694,05
9	Wien	9	0	1000	0	0
10	Milano	11	99964,37	600	1862,43	568,49
11	Brussels	13	692535,85	245	5268,56	1608,19
12	Lyon	16	525840,90	390	6368,00	1943,78
13	Barcelona	17	0	790	0	0
14	Madrid	18	471431,50	1005	14711,89	4490,69
15	Edinburgh	21	0	850	0	0
16	London	22	320084,92	340	3379,31	1031,51
17					------------------	----------------------
18				TOTALS:	55425,92	16918,34
19	help at H21 and N21					

Figure 3.5 Safety stock cost (from WCOST.XLS)

	A	B	C	D	E	F
1	CYCLE, SAFETY, AND PIPELINE STOCK CALCULATIONS					
2	ANNUAL STOCK COSTS FOR ENTIRE SYSTEM					
3						
4	item type	Avg. Lot Size		SSMOSi		Fraction of
5		(months of supply)		(from SAFE3P.XLS)		Annual Sales
6	A	0,50		0,09		0,80
7	B	1,00		0,12		0,15
8	C	3,00		0,65		0,05
9						
10	item type	Avg Cycle		Safety		Pipeline Stock
11		stock(Ecu)		stock(Ecu)		(Ecu)
12	A	842304,50		301892,04	From routes:	24486,06
13	B	315864,19		77727,86		
14	C	315864,19		136600,10	From London:	55425,92
15		-------------------		-------------------		-------------------
16		1474032,87		516220,00		79911,98

Table 3.6 Warehouse cost summary (from WCOST.XLS)

	A	B	C	D	E	F
1		COST SUMMARY:			ECU / Year	
2		Transportation:				
3			Long Haul	1455962,59		
4			Short Haul	2636145,85		
5				Total:	4092108,43	
6						
7		Warehouse costs:			24172484,86	
8						
9		Total Inventory:		2070164,85		
10		Interest Cost (at 20%):		*0,20 =	414032,97	
11					-------------------	
12		TOTAL COST OF SYSTEM:			28678626,26	
13						
14			Total Revenue:			83940542,92
15			Cost/manufactured sqm @ .313:			50525749,87
16			PRE-TAX NET INCOME:			4736166,79