LLENROC PLASTICS EUROPE\textsuperscript{1}: TEACHING NOTES

by

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\textsuperscript{1}The original case, Llenroc Plastics, was developed by P. Jackson and J. Muckstadt [1] at ORIE, Cornell University. Llenroc Plastics Europe is an adaptation of the original case to Europe.
Llenroc Plastics Europe\textsuperscript{1}:

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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. The paper "Llenroc Plastics Europe" describes different problems encountered during the analysis of the distribution system of the company.

This text proposes solutions for these problems, lists the main difficulties faced by the students during this case study and gives some hints for teaching this case.

\footnote{The original case, Llenroc Plastics, was developed by P. Jackson and J. Muckstadt \cite{Jackson1976} at ORIE, Cornell University. Llenroc Plastic Europe is an adaptation of the original case to Europe.}
1. REGIONAL TRANSPORT SYSTEM

The general question which is tackled in Case 1 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.

Assignment 1.1 How to define an economic model of transportation cost.

It will be necessary in Case 1 to compare transportation plans with different numbers of trucks which cover different distances within different times. We therefore need to determine the weekly cost $T$ of owning a truck, the cost $K$ per kilometer driven and the cost $H$ per driver hour. These three parameters can be derived from Table 1.1 of [2]. The main difficulty comes from the timing of cash flows: truck purchase occurs at the beginning of the year; truck sale is at the end of the fifth year; registration and insurance are beginning-of-year cash flows. We suggest to use a discounted cash flow approach (or the net present value) for the truck-related costs but not for the mileage or driver costs. Using the data given in Table 1.1 and a weekly interest rate of 12%52, we found

$$T = 323,73 \text{ ECU's/truck}, \quad K = 0.3 \text{ ECU's/km} \quad H = 15 \text{ ECU's/hours}$$

Two further refinements could be introduced: the cost analysis could be performed "after-tax" and the salary of the dispatcher in charge of the management of the trucking fleet could be introduced in the cost model.

Incorrect analysis for the weekly cost $T$ are very common. The tendency of summarizing all the costs in terms of kilometers or trucks only occurs also quite often. This is not necessary a mistake. However, the assumptions which are necessary to derive the cost parameters (the lifetime of a truck, for example) must be checked when applying this cost model to evaluate a transportation plan such as in assignments 1.2, 1.3 and 1.4.

Assignment 1.2 Daily shipment policy.

Many different solutions exist. The TRUCKS spreadsheet allows the burden associated with the evaluation of transportation plan to be reduced. Not only the feasibility of a plan can be checked but the corresponding covered distance and driving hours are automatically derived. The application of the cost model of assignment 1.1 immediately leads to a cost estimation.

It does not seem possible to use less than six trucks. Here is a good solution.

<table>
<thead>
<tr>
<th>Truck</th>
<th>Mon.</th>
<th>Tue.</th>
<th>Wed.</th>
<th>Thu.</th>
<th>Fri.</th>
<th>Mon.</th>
<th>Tue.</th>
</tr>
</thead>
</table>
The following points must be considered during the search for a good solution:

- **Week Ends.** Which assumptions can be made about driving during the weekend. Should we allow driving and delivering, driving only or no driving at all? Both the social and the economic consequences must be reviewed.

- **Cyclic Schedule.** The cyclicity of the schedule must be guaranteed. The trucks we need for Monday and Tuesday of the following week must be available.

- **Customer service.** How to derive or compute a global measure (average) of the delivery times. Note the role played by the direction (clockwise or counterclockwise) followed by a truck on a route.

- **Truck maintenance.** The need for maintaining the trucking fleet in good shape, its implementation and its cost are points which can be raised here.

We also asked the students to describe the methodology they followed to determine the best routing and scheduling. In order to avoid vagueness, we required this description to be so detailed that it could be almost directly programmed. We also asked how robust their solution was and how the cost would evolve if some slight variations in the demands would occur. It is important to recognize here how much their solution does depend on the data.

**Assignment 1.3 Consolidated shipment policy.**

Again, many solutions exist. They can be evaluated by means of the MGMT spreadsheet. Here is a good solution which requires three trucks only. Splitting the weekly demand in the following set of daily orders:

<table>
<thead>
<tr>
<th>A</th>
<th>City#</th>
<th>City</th>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thurs</th>
<th>Fri</th>
<th>Total</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Rotterdam</td>
<td>8780</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8780</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Paris</td>
<td></td>
<td>4012</td>
<td></td>
<td></td>
<td></td>
<td>4012</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Amiens</td>
<td></td>
<td></td>
<td>7090</td>
<td></td>
<td></td>
<td>7090</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Caen</td>
<td></td>
<td>20555</td>
<td>20556</td>
<td></td>
<td></td>
<td>41111</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>Brussels</td>
<td>20005</td>
<td></td>
<td></td>
<td></td>
<td>22500</td>
<td>42505</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>Reims</td>
<td></td>
<td></td>
<td>4100</td>
<td></td>
<td></td>
<td>4100</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>Metz</td>
<td>2367</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2367</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>Liege</td>
<td></td>
<td>13352</td>
<td></td>
<td></td>
<td></td>
<td>13352</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>Aachen</td>
<td>22500</td>
<td>243</td>
<td></td>
<td>22500</td>
<td></td>
<td>45243</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>Ostende</td>
<td></td>
<td>5554</td>
<td></td>
<td></td>
<td></td>
<td>5554</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>Groningen</td>
<td>5274</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5274</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>Amsterdam</td>
<td>4048</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4048</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>Luxembourg</td>
<td>8708</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8708</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>14</td>
<td>Trier</td>
<td></td>
<td>11580</td>
<td></td>
<td></td>
<td></td>
<td>11580</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>sum</td>
<td></td>
<td>62974</td>
<td>41086</td>
<td>13352</td>
<td>63812</td>
<td>22500</td>
<td>203724</td>
<td></td>
</tr>
</tbody>
</table>

allows the following routing/scheduling to be implemented:
<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck 1</td>
<td>Rotterdam / Amsterdam / Groningen</td>
<td></td>
<td>Brussels</td>
<td>Aachen</td>
<td>Liège</td>
</tr>
<tr>
<td>Truck 2</td>
<td>Brussel / Metz</td>
<td>Luxemburg / Trier / Aachen</td>
<td></td>
<td>Oost / Amiens / Paris / Reims</td>
<td></td>
</tr>
<tr>
<td>Truck 3</td>
<td>Aachen</td>
<td>Caen</td>
<td></td>
<td>Caen</td>
<td></td>
</tr>
</tbody>
</table>

Compared with the daily shipment policy, the number of trucks which is required is reduced by a factor 2. Cost reduction of about 60 percent can be achieved. The main concern is now the customer service since consolidated shipments imply delayed deliveries. The problem is thus to find ways to counteract this negative aspect in order to achieve the cost benefit. They should include considerations on fill rates, on customer types (OEM or distributors) and needs and on information systems. Besides the economic gain, the advantage of using a fixed schedule must be discussed.

We also asked the student to model the decisions as an optimization problem. The formulation of the problem as a mixed-integer linear program is made possible by the selection a priori of a set of routes. This selection is a possible discussion subject. There are different formulations of this problem depending on whether you want to emphasize customer service or cost and depending on how detailed you want to model truck scheduling. Here is a simple formulation.

Decision variables: 
- \( w_k \) = number of trips using route \( k \) each cycle;
- \( x_{ik} \) = number of square feet shipped to location \( i \) using route \( k \)
- \( z \) = overtime per cycle

Parameters:
- \( c \) = capacity of truck
- \( M_{ik} = M \) (large number) if location \( i \) is not on route \( k \); 0 otherwise;
- \( l_k \) = length of route \( k \) in hours of driver time
- \( a_k \) = cost of route \( k \): fuel cost and driver cost;
- \( g \) = overtime cost per hour (driver overtime premium)
- \( f \) = number of regular time driver hours per cycle.

Formulation (for fixed number of trucks and drivers):

\[
\min \sum_k a_k w_k + \sum_{i,k} M_{ik} x_{ik} + gz
\]

s.t.

\[
\sum_k x_{ik} = d_i; \quad \forall i \quad \text{(demand satisfaction)}
\]

\[
\sum_i x_{ik} \leq cw_k; \quad \forall k \quad \text{(truck capacity per cycle)}
\]

\[
\sum_k l_k w_k - z \leq f; \quad \text{(driver overtime)}
\]

\[
x_{ik} \geq 0; \quad \forall ik
\]

\[
w_k \in \{0,1,2,3,\ldots\}; \quad \forall k
\]

\[
z \geq 0.
\]

We also asked the students to provide a heuristic solution. Here is a solution: every location is assigned to one route; for location \( i \), pick the route with the smallest \( a_k/l_k \) ratio for which \( M_{ik} = 0 \).
A more complicated formulation is possible that tracks the day on which trucks leave, the route they follow, and the day they return. Variables include $y_{jt}$ (number of trucks following route $j$ beginning trip on day $t$) and $x_{ijt}$ (amount shipped to location $i$ on route $j$ with trip initiated on day $t$). Constraints include demand satisfaction, truck capacity, and daily truck availability. The objective function can include the total capital cost based on the number of trucks required.

**Assignment 1.4 and 1.5. Common carrier and recommendations.**

The main question here is "Why could a common carrier achieve a lower cost than Llenroc Plastics?" After all, they face the same or similar costs of trucks, distances and drivers. The difference comes from the backhaul: even if Llenroc’s trucks go out full as in the proposed solution with consolidated shipments, they return empty, often from considerable distances. The real company upon which this case is based attempted to find shipping business to fill trucks on the return trip to Brussels.

The impact of using a common carrier on customer service must be clearly evaluated. The carrier takes time to consolidate shipments just as in the demand management assignment (1.3). This time needs to be included in measures of customer wait time. We are looking for a verbal response to this question. The main goal here is to review the possible solutions and their relative advantages.

If students strongly favor keeping trucks (and most do), I note that the fixed routes they arrived at in assignment 1.3 could be used on a regular basis with good customer service and truck utilization even without knowing all the demands in advance. What has to be abandoned is the policy of sending a truck to satisfy every customer order on the day it is ready for shipment. The advantages of using a fixed route with a fixed schedule, even if it is only once a week, can be discussed at this point.

What did the company do in reality? They got out of the trucking business. They established a special relationship with what is called a contract carrier. Unlike a common carrier, a contract carrier is willing to provide specialized service depending on the client’s needs (Llenroc Plastics is the client). Llenroc was able to negotiate the kind of customer service it wanted the carrier to provide for a contract price that was considerably below their current cost of operating the fleet of trucks. Analysis similar to that conducted in this case was the basis for their negotiations. Note that the contract carrier is in the trucking business: it has many opportunities for backhaul and it can afford sophisticated data management and decision support software.

2. The Inventory Policy

**Assignment 2.1. The distribution games**

The precise assignment is to study the following one product two-echelon system

```
Production Plant

   Warehouse

      Retailer 1
      Retailer 2
      Retailer 3
```
with the following assumptions:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse: order cost</td>
<td>200 ECU's / order</td>
</tr>
<tr>
<td>Warehouse: holding cost</td>
<td>0.0735 ECU's / unit / day</td>
</tr>
<tr>
<td>Lead time (Production plant -&gt; warehouse)</td>
<td>15 days</td>
</tr>
<tr>
<td>Retailers: order cost</td>
<td>2.75 ECU's / order</td>
</tr>
<tr>
<td>Retailers: holding cost</td>
<td>0.0875 ECU's / unit / day</td>
</tr>
<tr>
<td>Lead time (warehouse -&gt; retailers)</td>
<td>5 days</td>
</tr>
<tr>
<td>Retailer demand distribution</td>
<td>uniform in {0,1,2,3,4}</td>
</tr>
<tr>
<td>Product selling price</td>
<td>100 ECU's</td>
</tr>
<tr>
<td>Product cost</td>
<td>70 ECU's</td>
</tr>
<tr>
<td>Unsatisfied demands</td>
<td>lost</td>
</tr>
</tbody>
</table>

The goal of this assignment is first to develop some feelings with a multi-echelon inventory system. With the game, INV_CTRL.XLS, the student can clearly identify the different aspects of the problem.

- First, the different inventory control notions such as the economical order quantity (EOQ), the safety stocks, the reorder point or the periodic review can be practised. The meaning of the different system parameters can also be reviewed here.
- The problematic related to the multi-echelon systems can then be introduced. Principles of synchronization and of fair allocation can be developed and illustrated.

The students must finally propose a daily inventory policy for the warehouse and the retailers. The proposal should be motivated mathematically.

The second game IN_CT_A.XLS (inventory control automate) allows (Q,R) policies (reorder point policy) to be simulated for a given period. The students are asked here to estimate the importance of the different system parameters: the variance of the demand distribution, the order costs, the lead times for both the warehouse and the retailers and the length of the review period. They are also asked to criticize the simple (Q,R) inventory policy used in the spreadsheet by considering the following aspects:

- the fact that order decisions are based on inventory position only;
- how these inventories are determined;
- the fixed size of the orders;
- how the retailer orders are modified when the warehouse inventory level does not allow all the retailer orders to be satisfied.

Here is a list of typical mistakes commonly made by the students during the solution of this assignment:

- Imprecise understanding of the holding cost rate at the lower echelons. The student often use the same value when they deal with retailer orders which are related to the difference of holding cost between the central warehouse and the retailers and with safety stock values which refer to the absolute holding cost.
- Incorrect (or unmotivated) use of the normal distribution. The students often do not realize they can simply compute convolutions of the uniform distribution or some do not know how to do this.
- Confusion between stockout probability and average number of unsatisfied demands. 99 percent of demand satisfied from the shelf or a stockout probability of 99% often seem to be the same for the students. Numerical examples are here needed to clarify this point.
• Use of a unique fixed value for the customer service. The students often define an a priori customer service level (95% for example) and do not ask themselves whether it makes sense. In some cases, a negative safety stock is proposed without realizing what it means.

• Forgotten review period (one day). The students often assume the control to be continuous.

• Incorrect analysis for the central warehouse. Often, rough assumptions are made on the demand process at the central warehouse.

A last important aspect of playing the two games is the ability to develop feelings on the kind of information which is necessary at each echelon to allow efficient inventory control policies to be implemented. This becomes obvious if the students are asked to determine the demand at the central warehouse. Whether we just look at the retailer orders or at the customer orders make the answers quite different.

Assignment 2.2 Demand analysis and safety stock computation

The following precise assignments are given to the students.

a) Perform an A-B-C categorization of these 70 items of table 2.1 based on sheets shipped and on square footage shipped. Note that since production cost and sales price per square foot are roughly the same for all products, an A-B-C analysis of square footage shipped is equivalent to an A-B-C categorization based on cost or revenue. The importance of these two categorizations with respect to inventory control and transportation can be discussed here.

b) Determine the safety stocks for the three items: Almond D 60x144, Almond P 36x120, and Pigeon Blue PF 48x96. For each item, plot safety stock as a function of fill rate. Start each plot with a 50% fill rate. How does the coefficient of variation of lead time demand affect safety stock requirements? Use the data of this assignment to illustrate your claim. Per unit of sales, which of the three items requires the greatest inventory investment in safety stock to achieve the same fill rate? Discuss the impact of the marketing strategy which pushes for more patterns.

c) To see the impact of lead time variability, assume that lead time is no longer constant but is either one week or three weeks, each with probability 0.5. The assumption of normally distributed demand is no longer valid in this context. However, for the purpose of illustration, first use the assumption of normality to determine safety stock requirements for this variable lead time case. Plot safety stock as a function of fill rate for the first item (Almond D 60x144) and compare the plot to the corresponding plot with constant lead time. Explain the difference.

A purpose of the case is to help the students understand why fill rates are so poor at the Brussels Distribution Center. The students do not need to recommend a strategy to improve fill rate performance yet. They must first conduct different A-B-C analyses. We typically provide a handout describing A-B-C analysis for students who have not been exposed to the concepts. The discussion in the text by Silver and Peterson referred to in the case is usually sufficient.

Students do recognize that the classification by number of sheets shipped makes more sense for inventory policies than a cost or square-foot measure of volume. One team didn't think ABC classification was a good idea and wanted to treat each item equally importantly and make stocking policies sensitive to more information than just average demand. We pointed out that it is simply a practical technique to cope with large amounts of data involved and that it does suggest different strategies to follow.

The following two graphs provide solutions for the b) part of the assignment. These are obtained by means of a spreadsheet named S3SP.XLS.
They illustrate that an A item requires more safety stock in absolute terms than a C item to achieve a high fill rate. However, relatively to the number of sheets sold, C items require more safety stock than an A or B item to achieve any reasonable fill rate. This coupled with the fact that there are many C items explains why the class of C items requires a safety stock investment that is disproportionate with its share of demand volume.

In the c) assignment, the students should find that the coefficient of variation increases with the square root of the lead time. They should also observe that safety stock increases with the coefficient of variation and that low volume items (high coefficient of variation items) require more safety stock per unit of sales than high volume items. They should also realize that item proliferation causes dramatic increases in safety stock requirements. This is why vending machines may store different flavors but will standardize on package size. (All soft drink cans are the same size.)
A very important discussion here is the reason for large variations in the demand. Lot sizing is indeed a very important source of variation. There are many legitimate reasons for the customers to batch their demand for Llenroc’s products. It has to do with the transactions costs of placing orders, receiving invoices and packing slips, and matching these invoices with original orders to authorize payment. The promise of EDI (electronic document interchange) is that these transactions costs should decline significantly thereby permitting customers to order more frequently and in smaller quantities. The demand process at the main warehouse in assignment 2.1 is a good illustration of this phenomenon.

We usually close the meeting by pointing out that Assignment 2.2 is an excellent preparation for the Assignment 3. The main lesson to draw from 2.2 is that even if the ultimate demand is fairly smooth, the lot sizing that our customers perform induces a considerable degree of variability into our order stream. Having worked the relationship between safety stock and the coefficient of variation, students immediately perceive the benefit in reduced safety stock that smaller order quantities will provide. We note to students that many of them will likely be working in the area of EDI in the coming decade. Some students ask if Llenroc has to buy the hardware and software to install in customers’ purchasing departments. The answer is no. There are emerging standards for EDI and it is in the interests of both manufacturers and distributors to purchase equipment for themselves to communicate with both customers and vendors. If EDI can be expanded to permit the transmission of production schedules and/or current inventory levels, then Llenroc Plastics will be better able to anticipate demand for its products, at least by the large customers.

3. The Warehouse System

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

Many students are initially overwhelmed with the apparent demands of Case 3. There are so many possible ways to locate warehouses that they are at a loss as to where to begin. We reassure them that we do not intend to have them investigate all possibilities. We tell them that if they think about the relationships there are only a small number of combinations that make sense. They need to understand the following relationships.

Begin with a focus on the impact of the number of warehouses on cost.

Does the number of warehouses affect warehousing costs? The answer is yes because the warehouse operating costs are related to volume. The more warehouses there are, the smaller will be the volume per warehouse. Does the warehouse cost function exhibit increasing or decreasing returns to scale? The students must look into the spreadsheet to find the answer to this. If it is decreasing returns to scale then warehousing costs will decline as we reduce the number of warehouses. If it is increasing returns to scale, then the reverse is true. Attached is a printout of WCOST.XLC that shows the warehousing cost function. We hand out a copy of this page to each team during the meeting. The function exhibits decreasing returns to scale. Therefore, reducing the number of warehouses will decrease warehousing costs.

Does the number of warehouses affect transportation costs? The answer is yes but since the product must travel from London to the customer anyway, the choice of regional warehouse location just adds some detours to that trip. It is not a major factor in total transportation cost.

How does the number of warehouses affect inventory investment? We need to answer this question for each category of inventory. Does it affect the amount of pipeline stock? As with transportation costs, the answer is yes but for the reason expressed in the previous paragraph, the location of warehouses is not going to greatly affect the amount of pipeline stock in the system. That is more a function of where we locate our manufacturing site(s) relative to where the customers are.

Does the number of warehouses affect the investment in cycle stock? We remind students that in the Assignment 2.1 they had to determine economic order quantities for regional warehouses. Why,
the Distribution Game, did we only charge (0.0875 - 0.0735) per unit-day of inventory at the regional warehouses when computing regional economic order quantities? After all, the full inventory holding cost was 0.0875 ECU's per unit-day. The reason is that given the order quantity at the central warehouse, if the cycle stock is not held at the regional warehouse it must be held at the central warehouse. The regional order quantity only affected where the cycle stock was held, not how much was held. Therefore, the appropriate holding cost was the incremental holding cost. Similarly, for Llenroc Plastics, the total amount of cycle stock in the system is determined by the order quantities placed at the central warehouse. The number of warehouses and the order quantities at the regional warehouses only affects the geographical distribution of cycle stock, not its total. (The differential holding cost in Llenroc Plastics is zero because we are modelling transportation and warehousing costs explicitly.) Consequently, cycle stock is unaffected by the number of warehouses.

How does the number of warehouses affect safety stock? Students generally recognize that safety stock must decrease if we reduce the number of warehouses. This is a good opportunity to discuss risk pooling with them. Table 2.1 clearly shows how the coefficient of variation decreases when we aggregate demand across regions. From Case 2, students recognize that this means a reduction in safety stock requirements. To make the discussion more analytical, we sometimes observe that if A and B are independent random variables then because $\sqrt{\sigma_A^2 + \sigma_B^2} \leq \sigma_A + \sigma_B$, we will have a smaller amount of safety stock to support demand A+B then we would need to support demand A and demand B separately. Table 2.1 shows dramatic reductions in coefficient of variation as we aggregate demand. Consequently, reducing safety stock requirements is a powerful incentive to reduce the number of warehouses. If the students keep a large number of regional warehouses and set the fill rate for B and C items to be very high at the regional warehouses, then the cost spreadsheet will show that Llenroc will lose money with this strategy ("we can provide great service until we run out of business").

We note to students that another way to reduce safety stock requirements without reducing the number of warehouses is to centralize the stocking of some items. For example, a possible strategy is to keep a large number of warehouses but only use them to stock A items. Under this strategy, stock the B and C items only at the central warehouse. The A items require very little safety stock (Case 2 illustrated this.) If customers ask a regional warehouse for a B or C item, then the order is simply transmitted immediately to the central warehouse. This can be modelled in the spreadsheet SAFETY.WK1 by setting a high fill rate for A items at the regional warehouses and a low fill rate for B and for C items at the regional warehouses.

While we are on the subject of fill rates, we tell the students that we will check their solutions to see that the lead times they specify between the central warehouse and the regional warehouses are consistent with the fill rates they have chosen. That is, if for C items, they set a very high fill rate at the central warehouse then the lead time at the regional warehouse will be close to the transportation time. However, if they set a low fill rate at the central warehouse, then the lead time from when a regional warehouse places an order to when they receive it will on average be greater than the transportation time because there is a good chance the item will not be in stock at the central warehouse and the regional warehouse will have to wait until that product is produced, a time that is measured in weeks. We don't expect a detailed analysis of this point but students should not ignore it. Students note that the variability of lead time will be high in this case with a consequent higher coefficient of variability of regional warehouse lead time demand. We agree but observe that the spreadsheet implements a very simple model of safety stock as a piece of a larger cost model.

As a result of the discussion so far, students will realize that the cost arguments will probably drive them to have as few warehouses as possible. The only argument in favor of many warehouses is customer service. Students will naturally think that to get good customer service we need warehouses close to the customers. To counter that bias, we ask them to think about what is meant by customer service. We are not in a retail business. That is, customers do not walk into our store and walk out if we don't have the product on the shelf. We sell to distributors and OEM's in most cases. These organizations place orders to replenish their inventories of our product. They are generally willing to wait some amount of time. Llenroc promises 20 days but can't make that even with all the warehouses they have now. Customer service will be determined by how long the customer is willing to wait, how long it takes to move the product from where we stock it to where the customer is, how frequently we make shipments to the area in which the customer is located, how high our fill rate is

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at the location where we stock the product, and, if this fill rate is less than 100%, how long it takes to fill a backorder at the location where we stock the product. Emphasize that frequency of shipment is an important factor in customer service and they should address it.

The last thing to observe is that customer service doesn’t have to be measured uniformly. Customers in Portugal or Ireland do not expect the same level of service as customers in France or Germany and it is not cost-effective to try to provide equivalent service. Although the case doesn’t raise the issue, different sized customers expect different levels of service as well.

These observations are to balance the bias towards locating warehouses close to the customer. We note that that is typically what the marketing department wants to do and that is why Llenroc has so many warehouses.

There is no one right answer to how many warehouses Llenroc should have. It depends on how you measure customer service and what cost you are willing to incur to provide that service. It is clear however, that Llenroc could provide good customer service with significantly fewer warehouses than the number currently in place. If the students limit themselves to a small number of warehouses, there are only a few combinations of locations that they will need to investigate before they can make an intelligent recommendation.

In order to reduce the computational burden associated with this assignment, the spreadsheet WCOST.XLS has been developed. The students are first required to define where warehouses will be located and which regions each of them will serve. This define the warehouse costs and the transportation cost from the central warehouse to the regional warehouses. The specification of the routes for delivering each region from its assigned warehouse determines the short haul transportation cost. All these transportation plans also allow the pipeline stock costs to be estimated. Finally, the selection of the order quantities and of the safety stocks along with an ABC classification allows the safety stock costs and the cyclic costs to be determined.
